BULLETIN

OF THE

PHILOSOPHICAL SOCIETY

OF

WASHINGTON

VOL. 13

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CONSTITUTION

OF

THE PHILOSOPHICAL SOCIETY OF WASHINGTON.

Article I. The name of this Society shall be The Philosophical Society of Washington.

Article II. The officers of the Society shall be a President, four Vice-Presidents, a Treasurer, and two Secretaries.

Article III. There shall be a General Committee, consisting of the officers of the Society and nine other members and such of the Past Presidents of the Society resident in Washington and retaining membership as shall annually, before the first meeting of February of any year, notify the Secretary of the General Committee of their intention to attend its meetings or whose presence may be requested by a vote of the committee.*

Article IV. The officers of the Society and the nine other members of the General Committee shall be elected annually by ballot; they shall hold office until their successors are elected, and shall have power to fill vacancies.

Article V. It shall be the duty of the General Committee to make rules for the government of the Society, and to transact all its business.

Article VI. This Constitution shall not be amended except by a three-fourths vote of those present at an annual meeting for the election of officers, and after notice of the proposed change shall have been given in writing at a stated meeting of the Society at least four weeks previously.

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* As amended December 23, 1899.

STANDING RULES

FOR THE GOVERNMENT OF

THE PHILOSOPHICAL SOCIETY OF WASHINGTON.

AS AMENDED MAY 7, 1887.

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1. The Stated Meetings of the Society shall be held at 8 o'clock p. m. on every alternate Saturday; the place of meeting to be designated by the General Committee.

2. Notice of the time and place of meeting shall be sent to each member by one of the Secretaries.

When necessary, Special Meetings may be called by the President.

3. The Annual Meeting for the election of officers shall be the last stated meeting in the month of December.

The order of proceedings (which shall be announced by the Chair) shall be as follows:

First, the reading of the minutes of the last Annual Meeting.

Second, the presentation of the annual reports of the Secretaries, including the announcement of the names of members elected since the last Annual Meeting.

Third, the presentation of the annual report of the Treasurer.

Fourth, the announcement of the names of members who, having complied with section 14 of the Standing Rules, are entitled to vote on the election of officers.

Fifth, the election of President.

Sixth, the election of four Vice-Presidents.

Seventh, the election of Treasurer.

Eighth, the election of two Secretaries.

Ninth, the election of nine members of the General Committee.

Tenth, the consideration of Amendments to the Constitution of the Society, if any such shall have been proposed in accordance with article VI of the Constitution.

Eleventh, the reading of the rough minutes of the meeting.

4. Elections of officers are to be held as follows:

In each case nominations shall be made by means of an informal ballot, the result of which shall be announced by the Secretary; after which the first formal ballot shall be taken.

In the ballot for Vice-Presidents, Secretaries, and Members of the General Committee, each voter shall write on one ballot as many names as there are officers to be elected, viz., four on the first ballot for Vice-Presidents, two on the first for Secretaries, and nine on the first for Members of the General Committee, and on each subsequent ballot as many names as there are persons yet to be elected; and those persons who receive a majority of the votes cast shall be declared elected: *Provided*, That the number of persons receiving a majority does not exceed the number of persons to be elected, in which case the vacancies shall be filled by the candidates receiving the highest majorities.

If in any case the informal ballot result in giving a majority for any one, it may be declared formal by a majority vote.

5. The Stated Meetings, with the exception of the Annual Meeting, shall be devoted to the consideration and discussion of scientific subjects.

The Stated Meeting next preceding the Annual Meeting shall be set apart for the delivery of the President's Annual Address.

6. Sections representing special branches of science may be formed by the General Committee upon the written recommendation of twenty members of the Society.

7. Persons interested in science, who are not residents of the District of Columbia, may be present at any meeting of the Society, except the Annual Meeting, upon invitation of a member.

8. On request of a member, the President or either of the Secretaries may, at his discretion, issue to any person a card of invitation to attend a specified meeting. Five cards of invitation

to attend a meeting may be issued in blank to the reader of a paper at that meeting.

9. Invitations to attend during three months the meetings of the Society and participate in the discussion of papers may, by a vote of nine members of the General Committee, be issued to persons nominated by two members.

10. Communications intended for publication under the auspices of the Society shall be submitted in writing to the General Committee for approval.

11. Any paper read before a Section may be repeated, either entire or by abstract, before a general meeting of the Society, if such repetition is recommended by the General Committee of the Society.

12. It is not permitted to report the proceedings of the Society or its Sections for publication, except by authority of the General Committee.

13. New members may be proposed in writing by three members of the Society for election by the General Committee; but no person shall be admitted to the privileges of membership unless he signifies his acceptance thereof in writing, and pays his dues to the Treasurer, within two months after notification of his election.

14. Each member shall pay annually to the Treasurer the sum of five dollars, and no member whose dues are unpaid shall vote at the Annual Meeting for the election of officers, or be entitled to a copy of the Bulletin.

In the absence of the Treasurer, the Secretary is authorized to receive the dues of members.

The names of those two years in arrears shall be dropped from the list of members.

Notice of resignation of membership shall be given in writing to the General Committee through the President or one of the Secretaries.

15. The fiscal year shall terminate with the Annual Meeting.

16. Any member who is absent from the District of Columbia for more than twelve consecutive months may be excused from payment of dues during the period of his absence, in which case he will not be entitled to receive announcements of meetings or current numbers of the Bulletin.

17. Any member not in arrears may, by the payment of one hundred dollars at any one time, become a life member, and be relieved from all further annual dues and other assessments.

All moneys received in payment of life membership shall be invested as portions of a permanent fund, which shall be directed solely to the furtherance of such special scientific work as may be ordered by the General Committee.

STANDING RULES

OF

THE GENERAL COMMITTEE

OF

THE PHILOSOPHICAL SOCIETY OF WASHINGTON.

AS AMENDED NOVEMBER 12, 1898.

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1. The President, Vice-Presidents, and Secretaries of the Society shall hold like offices in the General Committee.

2. The President shall have power to call special meetings of the Committee, and to appoint Subcommittees.

3. The Subcommittees shall prepare business for the General Committee, and perform such other duties as may be entrusted to them.

4. There shall be six Standing Subcommittees:

I. On Communications.
II. On Publications.
III. On Grants.
IV. On Mathematical Science.
V. On Physical Science.
VI. On General Science.

5. The General Committee shall meet at half-past seven o'clock on the evening of each Stated Meeting, and by adjournment at other times.

6. Six members shall constitute a quorum for all purposes, except for the amendment of the Standing Rules of the Committee and of the Society.

7. The names of proposed new members recommended in conformity with Section 13 of the Standing Rules of the Society

may be presented at any meeting of the General Committee, but shall lie over for at least two weeks before final action. No rejected candidate shall be eligible to membership within twelve months from the date of rejection. The Secretary of the General Committee shall keep a chronological register of the elections and acceptances of members.

An affirmative vote of three-quarters of the members present shall be necessary to an election.

8. These Standing Rules, and those for the government of the Society, shall be modified only with the consent of a majority of the members of the General Committee, but by unanimous consent of a quorum any rule except numbers 6 and 7 of the Standing Rules of the General Committee may be temporarily suspended.

RULES RESPECTING PUBLICATIONS

OF

THE PHILOSOPHICAL SOCIETY OF WASHINGTON.

ADOPTED DECEMBER 22, 1888.

1. The regular publication of the Society shall have the form of a series of completed papers or memoirs, to which the transactions of the Society shall be added. Publication shall not be made at stated intervals, but whenever directed by the General Committee.

2. Each paper read before the Society and offered for publication shall be at once referred to a special committee of two appointed by the President, which shall submit to the General Committee at its next meeting a written report on the paper, and the General Committee shall decide respecting its publication. The annual address of the retiring President and the annual reports of the Treasurer and Secretaries shall be published in full, without reference. The journal of the Society shall be published in condensed form at the end of the volume.

3. Papers read before a Section of the Society and offered for publication shall be referred to a committee appointed as the Section may direct. The paper, accompanied by a written report, shall be laid before the General Committee, which shall decide respecting publication.

4. Papers approved by the General Committee for publication shall be printed forthwith, and one hundred copies shall be gratuitously furnished to the author.

5. The papers published from time to time shall be paged consecutively, and when sufficient material has accumulated to form a volume of convenient size, a title page, table of contents, and index shall be prepared, and the whole issued as a volume of the Bulletin of the Philosophical Society.

ADDITIONAL ACTIVITIES FOR THE SOCIETY.

REPORT OF A SPECIAL COMMITTEE, COMPOSED OF

F. H. BIGELOW, J. HOWARD GORE, AND W. H. DALL.

Submitted, Amended, and Adopted in the Following Form at the 490th Meeting of General Committee, November 26, 1898.

It is proposed to assume some additional functions, and in nowise to abandon any ground now held by the Society. The general scope of science and exact knowledge may be cultivated, not only by the reading and discussion of papers explaining the researches carried out by individuals, as in the past, but also by direct agencies tending to promote science where it most needs active work; therefore,

I. *Resolved*, That three standing committees be appointed annually, as follows:

1. Committee on *Mathematical Science*, including Astronomy, Geodesy, Mechanics, and allied subjects.
2. Committee on *Physical Science*, including Electricity and Magnetism, Meteorology, Terrestrial Magnetism, and kindred topics.
3. Committee on *General Science*, including subjects not reserved for the other committees but suitable for discussion by this Society.

The chairmen of these committees shall be chosen annually by a majority vote of the General Committee; the members shall be appointed by the chairmen of the same from the Society at large, and associate members from outside the roll of the Society may also be added, if desired. These committees shall each make a specific report annually upon one or more of their special topics, which shall be published in the Bulletin, stating the recent progress and the desiderata of science in the respective branches. They shall also, under the direction of the Commit-

tee on Communications, bring before the Society from time to time popular statements and illustrations of matters of interest likely to be of value to the members of the Society. They shall especially seek to enlist the active coöperation of those who are working along the same lines of research, where such mutual support will be likely to promote scientific discoveries.

II. *Resolved*, That there shall be a Committee on *Grants in Aid of Research*, to be composed of three members, appointed by the President, to serve for one year like the other standing committees.

The duties of this committee shall be to receive applications for grants, to consider them, and in such cases as they may approve, to report the same to the Council for action. Applications disapproved shall not be reported to the Council unless it is so requested by the applicant: *Provided*, That the committee may call upon any member of the Society for advice or information in any case where they may deem it advisable, and that all such communications shall be regarded as confidential unless communicated to the Council by vote of the committee: *Provided*, That the membership of this committee shall be announced to the Society at the next meeting after its appointment, by the incoming President of each year: *Provided*, That the committee shall make such rules in regard to the matter of applications and publication of results as they may deem proper, the same to be approved by the Council of the Society before going into effect.

It frequently happens that a member of the Society has in mind some query which he would like to have answered, but is uncertain as to the person to whom he should address himself; again, it sometimes occurs that a member has devised some method of solution, or made a discovery of interest, but not of sufficient importance to warrant its elaboration in a set paper; therefore,

III. *Resolved*, That to give a hearing to persons of either of the classes named, the first half-hour of each regular meeting shall be reserved for informal communications, when any member may propose for answer or discussion such topic or question as he has under consideration.

IV. *Resolved*, That an electric lantern be procured and kept permanently in place for use in illustrating the work of authors who present communications.

PRESIDENTS OF THE SOCIETY.

*JOSEPH HENRY	1871–'78.
SIMON NEWCOMB	1879–'80.
*J. J. WOODWARD	1881.
*W. B. TAYLOR	1882.
J. W. POWELL	1883.
*J. C. WELLING	1884.
ASAPH HALL	1885.
J. S. BILLINGS	1886.
WM. HARKNESS	1887.
*GARRICK MALLERY	1888.
J. R. EASTMAN	1889.
C. E. DUTTON	1890.
T. C. MENDENHALL	1891.
G. K. GILBERT	1892.
*G. BROWN GOODE	1893.
ROBERT FLETCHER	1894.
W. H. DALL	1895.
F. W. CLARKE	1896.
MARCUS BAKER	1897.
F. H. BIGELOW	1898.
O. H. TITTMANN	1899.
G. M. STERNBERG	1900.

*Deceased.

OFFICERS

OF

THE PHILOSOPHICAL SOCIETY OF WASHINGTON, 1900.

(ELECTED DECEMBER 23, 1899.)

President	G. M. STERNBERG.	
Vice-Presidents	H. S. PRITCHETT.	C. D. WALCOTT.
	RICHARD RATHBUN.	LESTER F. WARD.
Treasurer	B. R. GREEN.	
Secretaries	E. D. PRESTON.	J. ELFRETH WATKINS.

MEMBERS AT LARGE OF THE GENERAL COMMITTEE.

CYRUS ADLER. G. W. LITTLEHALES. F. W. TRUE.
W. A. DE CAINDRY. C. F. MARVIN. C. K. WEAD.
J. HOWARD GORE. H. M. PAUL. ISAAC WINSTON.

STANDING COMMITTEES.

I. *On Communications:*

J. HOWARD GORE, Chairman.
J. F. HAYFORD. C. F. MARVIN.

II. *On Publications:*

MARCUS BAKER, Chairman.
G. W. LITTLEHALES. J. ELFRETH WATKINS.

III. *On Grants:*

RICHARD RATHBUN, Chairman.
BERNARD R. GREEN. H. S. PRITCHETT.
O. H. TITTMANN.

IV. *On Mathematical Science:*

J. F. HAYFORD, Chairman.
J. G. HAGEN. F. G. RADELFINGER.
T. J. J. SEE.

V. *On Physical Science:*

G. W. LITTLEHALES, Chairman.
CLEVELAND ABBE. L. J. BRIGGS. C. F. MARVIN.
L. A. BAUER. R. A. FESSENDEN. L. P. SHIDY.
F. H. BIGELOW. R. A. HARRIS. C. K. WEAD.

VI. *On General Science:*

W. H. DALL, Chairman.
CYRUS ADLER. WHITMAN CROSS. G. K. GILBERT.
F. W. CLARKE. HERBERT FRIEDENWALD. BERNARD R. GREEN.
J. ELFRETH WATKINS.

LIST OF MEMBERS

OF

THE PHILOSOPHICAL SOCIETY OF WASHINGTON,

TOGETHER WITH

YEAR OF ADMISSION TO THE SOCIETY, POST-OFFICE ADDRESS, AND RESIDENCE.

Corrected to July 1, 1900.

ACTIVE MEMBERS.

1871. ABBE, CLEVELAND,		
	Weather Bureau.	2017 I street.
1875. ABERT, S. T. (Silvanus Thayer),		
	Metropolitan Club.	725 Eighteenth street.
1881. ADAMS, HENRY,		
	1603 H street.	1603 H street.
1893. ADLER, CYRUS,		
	Smithsonian Institution.	943 K street.
1876. BAKER, MARCUS,		
	Geological Survey.	1905 Sixteenth street.
1888. BAUER, L. A. (Louis Agricola),		
	Coast and Geodetic Survey.	1925 I street.
1879. BELL, A. GRAHAM (Alexander Graham),		
		1331 Connecticut ave.
1890. BIGELOW, FRANK H. (Frank Hagar),		
	Weather Bureau.	1625 Massachusetts avenue.
1899. BLISS, LOUIS D. (Louis Denton),		
	614 Twelfth street.	1443 Chapin street.
1892. BLOUNT, H. F. (Henry Fitch),		
	1405 G street.	"The Oaks," 3101 U street.
1898. BRIGGS, LYMAN J. (Lyman James),		
	Department of Agriculture.	56 S street.

1897. BROCKETT, PAUL,
National Museum. 3425 Holmead avenue.

1886. BRYAN, J. H. (Joseph Hammond),
818 Seventeenth street. 1644 Connecticut avenue.

1879. BURNETT, SWAN M. (Swan Moses),
916 Farragut square.

1874. BUSEY, SAMUEL C. (Samuel Clagett),
1545 I street. 901 Sixteenth street.

1891. CARR, W. K. (William Kearny),
1008 F street. 1413 K street.

1896. CASANOWICZ, I. M. (Immanuel Moses),
National Museum. 1104 Sixth street.

1874. CHICKERING, J. W. (John White),
The Portner, 15th and U streets.

1877. CLARK, EDWARD,
Architect's Office, Capitol. 417 Fourth street.

1874. CLARKE, F. W. (Frank Wigglesworth),
Geological Survey. 1612 Riggs place.

1889. CROSS, WHITMAN (Charles Whitman),
Geological Survey. 2138 Bancroft place.

1871. DALL, WM. H. (William Healey),
Smithsonian Institution. 1119 Twelfth street.

1880. DAVIS, CAPT. C. H. (Charles Henry), U. S. N.,
Naval Observatory.

1881. DE CAINDRY, WM. A. (William Augustin),
Commissary General's Office, War Dept. 1816 H street.

1896. DODGE, CHARLES R. (Charles Richards),
Department of Agriculture. 1336 Vermont avenue.

1872. DUTTON, MAJ. C. E. (Clarence Edward), U. S. A.,
War Department. Army and Navy Club.

1884. EIMBECK, WILLIAM,
Coast and Geodetic Survey. 1014 Fourteenth street.

1881. FARQUHAR, HENRY,
Department of Agriculture. West Brookland, D. C.

1890. FISCHER, E. G. (Ernst Georg),
Coast and Geodetic Survey. 436 New York avenue.

1893. FISCHER, L. A. (Louis Albert),
Coast and Geodetic Survey. 923 Massachusetts ave.

1873. FLETCHER, ROBERT,
Army Medical Museum. The Portland.

1881. Flint, Dr. J. M. (James Milton), U. S. N.,
Smithsonian Institution. The Portland.

1896. Flynn, Harry F. (Harry Franklin),
Coast and Geodetic Survey. 1701 Sixth street.

1897. Friedenwald, Herbert,
Library of Congress. 943 K street.

1875. Gallaudet, E. M. (Edward Miner),
Deaf Mute College, Kendall Green NE.

1893. Garriott, E. B. (Edward Bennett),
Weather Bureau. 1248 Princeton street.

1894. Gates, Elmer,
Chevy Chase, Md.

1873. Gilbert, G. K. (Grove Karl),
Geological Survey.

1880. Gore, J. Howard (James Howard),
Columbian University. 237 R street NE.

1879. Green, Bernard R. (Bernard Richardson),
Library of Congress. 1738 N street.

1889. Hagen, J. G. (John George),
Georgetown College Observatory.

1871. Harkness, Prof. William, U. S. N.,
Naval Observatory. Cosmos Club.

1891. Harris, R. A. (Rollin Arthur),
Coast and Geodetic Survey. 49th and Albany sts.

1886. Hayden, Ensign Everett, U. S. N.,

1889. Hayford, J. F. (John Fillmore),
Coast and Geodetic Survey. 1514 Howard avenue.

1885. Hodgkins, H. L. (Howard Lincoln),
Columbian University. 1830 T street.

1898. Hodgkins, William C. (William Candler).
Coast and Geodetic Survey.

1874. Howell, Edwin E. (Edwin Eugene),
612 Seventeenth street. 2032 G street.

1879. Johnson, Joseph Taber,
926 Seventeenth street. 924 Seventeenth street.

1884. Kauffmann, S. H. (Samuel Hay),
1101 Pennsylvania avenue. 1421 Massachusetts ave.

1875. King, A. F. A. (Albert Freeman Africanus),
1315 Massachusetts avenue.

1887. LANGLEY, S. P. (Samuel Pierpont),
Smithsonian Institution. Metropolitan Club.

1895. LINDENKOHL, ADOLPHUS,
Coast and Geodetic Survey. 19 Fourth street. SE.

1898. LITTLE, F. M. (Frank Milton),
Coast and Geodetic Survey. 111 C street NE.

1889. LITTLEHALES, G. W. (George Washington),
Hydrographic Office. 2132 Leroy place.

1891. McCAMMON, JOS. K. (Joseph Kay),
1420 F street. 1324 Nineteenth street.

1883. McGEE, W J,
Bureau of American Ethnology. 1620 P street.

1879. McGUIRE, F. B. (Frederick Bauders),
1419 G street. 1333 Connecticut avenue.

1885. MANN, B: PICKMAN (Benjamin Pickman),
Patent Office. 1918 Sunderland place.

1886. MARTIN, ARTEMAS,
Coast and Geodetic Survey. 1534 Columbia street.

1885. MARVIN, C. F. (Charles Frederick),
Weather Bureau. 1404 Binney street.

1897. MAYNARD, GEO. C. (George Colton),
National Museum. 1407 Fifteenth street.

1886. MERRIAM, C. HART (Clinton Hart),
Department of Agriculture. 1919 Sixteenth street.

1886. MITCHELL, HENRY,
Santa Barbara, California. Nantucket, Mass.

1871. NEWCOMB, PROF. SIMON, U. S. N.,
1620 P street.

1879. NORDHOFF, CHARLES,
Coronado, San Diego county, California.

1885. NOTT, CHARLES C. (Charles Cooper),
Court of Claims. 826 Connecticut avenue.

1884. OGDEN, H. G. (Herbert Gouverneur),
Coast and Geodetic Survey. 1610 Riggs place.

1896. PAGE, JAMES,
Hydrographic Office. 1836 California avenue.

1871. PARKE, GEN. JOHN G. (John Grubb), U. S. A.,
16 Lafayette square.

1877. PAUL, H. M. (Henry Martyn),
Navy Department. 2015 Kalorama avenue.

1874. PEALE, A. C. (Albert Charles),
National Museum. 1010 Massachusetts avenue.

1896. PHILLIPS, W. F. R. (William Fowke Ravenel),
Weather Bureau. 1418 L street.

1884. POINDEXTER, W. M. (William Mundy),
806 Seventeenth street.

1874. POWELL, J. W. (John Wesley),
Bureau of American Ethnology. 910 M street.

1892. POWELL, W. B. (William Bramwell),
Franklin School. 1404 M street.

1888. PRESTON, E. D. (Erasmus Darwin),
Coast and Geodetic Survey. 44 M street.

1879. PRITCHETT, H. S. (Henry Smith),
Coast and Geodetic Survey. 1524 P street.

1892. PUTNAM, G. R. (George Rockwell),
Coast and Geodetic Survey.

1898. RADELFINGER, F. G. (Frank Gustav),
Le Droit Building, 802 F street. 912 S street.

1882. RATHBUN, RICHARD,
Smithsonian Institution. 1622 Massachusetts avenue.

1871. SAVILLE, J. H. (James Hamilton),
1420 Seventeenth street.

1871. SCHOTT, C. A. (Charles Anthony),
Coast and Geodetic Survey. 212 First street SE.

1890. SEARLE, G. M. (George Mary),
Catholic University of America.

1899. SEE, T. J. J. (Thomas Jefferson Jackson),
Naval Observatory. 2715 N street.

1895. SHIDY, L. P. (Leland Perry),
Coast and Geodetic Survey. 1617 Marion street.

1891. SMILLIE, THOS. W. (Thomas William),
National Museum. 1808 R street.

1876. SMITH, CAPT. DAVID, U. S. N.,
Navy Department. 1714 Connecticut avenue.

1880. SMITH, EDWIN,
Coast and Geodetic Survey. Rockville, Maryland.

1896. STERNBERG, GEN. GEORGE M. (George Miller), U. S. A.,
War Department. 1019 Sixteenth street.

1900. STETSON, GEORGE R. (George Rochford),
1441 Massachusetts avenue.

1900. STROTHER, R. H. (Robert Henry),
Patent Office. 861 M street.

1896. TAYLOR, NAVAL CONSTR. D. W. (David Watson),
Navy Department. 1640 Twenty-first street.

1888. TITTMANN, O. H. (Otto Hilgard),
Coast and Geodetic Survey. 1617 Riggs place.

1890. TRUE, A. C. (Alfred Charles),
Department of Agriculture. 1604 Seventeenth street.

1882. TRUE, FREDERICK W. (Frederick William),
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1899. UPDEGRAFF, MILTON,
Naval Observatory.

1883. WALCOTT, C. D. (Charles Doolittle),
Geological Survey. 2113 S street.

1889. WATKINS, J. ELFRETH (John Elfreth),
National Museum. 1626 S street.

1894. WEAD, C. K. (Charles Kasson),
Patent Office. 1709 Seventeenth street.

1889. WHITE, DR. C. H. (Charles Henry), U. S. N.,
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1891. WINSTON, ISAAC,
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1895. WOODS, ELLIOTT,
Architect's Office, Capitol. Congressional Hotel.

1874. YARROW, DR. H. C. (Harry Crècy),
814 Seventeenth street.

1897. YATES, CHARLES C. (Charles Colt),
Coast and Geodetic Survey.

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1885. Wright, Geo. M. (George Mitchell).
1887. Würdemann, H. V. (Harry Vanderbilt).
1884. Yeates, W. S. (William Smith).
1885. Ziwet, Alexander.

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Absent members	73
Total	178

CENTRAL AMERICAN RAINFALL.

BY

Mark Walrod Harrington.

[Read before the Society March 2, 1895.]

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1. *The Observations.*—The best series of rainfall observations in Central America is that taken at San José, Costa Rica. The series is a long one, and in its last three years the observations were taken with the outfit and under the conditions and requirements for a station of the first order, as agreed upon by the international committee representing the chief government weather services. This means that the record of the principal elements is made automatically, and also that it is published *in extenso*. The observatory is conducted by Professor Enrique Pittier. The next best series of rainfall observations is that of Dr. Earl Flint at Rivas, on the western shore of Lake Nicaragua. Here we have an uninterrupted series for fifteen years taken by the same observer, and this observer an educated physician who takes especial interest in problems of rainfall. Next to these come the observations made along the course of the Panama

canal. Of these we have nineteen years at Colon or Aspinwall, six years at Gamboa, on the watershed, and fourteen years at Panama, Naos island, and Taboga island. Naos is a small island in the Gulf of Panama, about a mile south of the town, and Taboga is a larger island, about 10 miles south. The last six years of the observations at Colon and all those at Gamboa and Naos island were taken under the rules of the French meteorological service.

The series at Guatemala City come next in order of importance. They were apparently taken with care, although by several different persons, and in part were cared for by the director of the astronomical observatory. At Belize the number of years is greater, but the series is much broken, beginning in 1848 and ending in 1894. There are probably fortyfive years of rainfall observations at Belize existing, but they do not seem to have been consulted by any meteorologist who has discussed the Central American rainfall, are apparently not in print, and no trace of them was found when I visited that city several years ago. Most of them will probably be found among the papers of Judge S. Cockburn, who took great interest in the rainfall of the colony. I have been able to use a publication of his for private circulation, with manuscript additions, sent to the Smithsonian Institution in 1870.

The records of a few years' observations at San Salvador, taken in connection with an astronomical observatory, have been published. At the remaining points (twentyone in number, making thirtyone stations in all; see Table I) the observations are more fragmentary, the usual guarantees of minute care are generally lacking, and our information about details is incomplete. These observations have been dug out from many publications, chiefly the *Meteorologische Zeitschrift* and the dozen or so government reports on the various proposed canals from Darien to Honduras. In Alta Verapaz, a recently formed province of Guatemala, Dr. Karl Sapper has lately established a series of stations among the coffee planters to study the remarkable rainfall of that district. With one station (Salamá) in Baja Verapaz he has

ten in all, nine in Alta Verapaz. The latter department is on the northern slope of an eastern and western mountain range, apparently the Sierra de las Minas of the maps, but if so the maps are wrong or the range has moved 15′ or 20′ north in latitude since the maps were made; but there are many things on the maps of Guatemala which are not in Guatemala itself, and *vice versa*. As the reports from the various stations in Alta Verapaz are fragmentary, I have generally combined them into one and used that as a representative value.

There is, so far as I am informed, not a rainfall observation from the Republic of Honduras, and I have therefore pieced out my information there by reports of travelers, especially Squier, and by statements made to me when I visited that country some years ago.

The information along the proposed routes of the Nicaragua canal is considerable, though fragmentary, except at Rivas. At San José Dr. Pittier established three outlying stations, at one of which, Heredia, observations had been taken before. Of these three stations Agua Caliente proves very interesting, as it has a transition rainfall between that of the eastern and western coasts.

Of those who have previously studied the Central American rainfall we may mention the papers of Dr. Moritz Wagner,* Dr. A. von Frantzius,† Pittier,‡ and the more general studies shown in rainfall publications of Schott, of Loomis, and those of Koeppen § and Hann.||

2. *General Geographic Conditions.*—From Darien to Yucatan stretches a narrow, irregular land surface, washed on

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*Beiträge zur meteorologie und klimatologie von Mittel-Amerika. 4°. Dresden, 1864, 31 pp. Separate from vol. 31 of Verh. der kais. L. C. deutschen akademie der naturforscher.

† Versuch einer wiss. begründung der klimat. verhältnisse Central Amerika's. *In* Zeitschrift für erdkunde. 8°. Berlin, 1868, pp. 289–319.

‡ Annales del instituto fisico-geografico, etc. 4°. San Jose de C. R., 189—.

§ Berghaus' physik. atlas. fol. Gotha, 1887. Abtheil. III, 1887, Atlas der meteorologie.

|| Handbuch der klimatologie. 12°. Stuttgart, 1883.

each side by a tropical sea. It extends through ten degrees of latitude (from 8° north to 18° north) and is 1,200 miles long by from 30 to 300 miles broad. It has an average width of 150 miles and a population of 18 per square mile—a density closely equal to that of the United States as a whole, including Alaska, or that of Minnesota or Kansas. Through the center of this band runs a backbone of mountains, generally less than 10,000 feet high, and for full half of the distance less than 6,000 feet, sometimes descending to moderate hills, at others expanding fan shaped to form extensive plateaus of 3,000 feet or more. The coasts are rarely high, and along a considerable part of them is an area little above sealevel, marked by lagoons and floods. Generally this strip is narrow, but along the Mosquito Coast for a distance of 300 miles it has a breadth of 100 to 150 miles. The western versant is more rapid than the eastern.

Over this area, twice in its annual course, the sun occupies the zenith at noon. Except for the variations caused by the sun's annual motion the whole east coast is reached by the northeast trades, and these in many places appear to cross the divide and descend on the western side. None of the mountains are so high as to have perpetual snow, and on only a few in the north is there a regular snowfall in winter. The division into temperature zones here is better marked than in Mexico. The lowest is the hot zone, along the coast to elevations of 300 to 400 feet. It is hot, humid, marshy, and malarial, and especially along the Atlantic side makes one of the hottest regions in the world, though its reputation for especial unhealthfulness does not appear to be justified. This zone is the home of the banana. The second extends up to 3,500 feet, is warm and vernal, only moderately well watered, and is the home of the coffee tree and pineapple. The third is cool, rather dry, the home of the cereals and the fruits of the temperate zone, while the sugarcane and cotton are found in its lower altitudes and the upper of the preceding zone. These two zones form the most thickly populated part of Central America and are entirely salu-

brious. They are often classed together as the *tierra templada.* The last is the cold zone, above 7,500 feet, where precipitation is scanty, frosts abound, and snow is no rarity.

The rainfall in this region is typically tropical and follows the sun, giving a dry season when the sun is south of the equator and a wet season when he is north, and giving a maximum rainfall in or near the month when he is in the zenith of the station of observation. This means two maxima per year; so that there are two rainy seasons, with a long and a short interval between them. The long dry season is in the months corresponding to our winter and spring, and is called the *verano.* It extends from December to April. The wet season is from May to November, and is called the *invierno,* while the short drier season is in August, and is called the *veranillo* or little *verano;* also the *verano de Augosto.* As a simple means of distinguishing these seasons, *verano* (long dry), *invierno* (wet), and *veranillo* (short dry) will be used.

Following the seasons through, we have this succession: Beginning with the height of the *verano,* in April, the weather is serene, clear, and the hottest of the year. On the plateaus it is delightful. With May or June the rainy season (*invierno*) sets in. It is due to local storms, with a striking diurnal course. The morning is cool and fresh. In the later hours of the forenoon cumulus clouds begin to appear about the mountain peaks, and are specially picturesque when hanging about volcanoes. They steadily grow and spread until cirrus streaks begin to extend from their tops, their bases become dark and threatening, and finally, late in the afternoon, the lightning flashes brilliantly, the thunder is loud and startling in its suddenness, and cataracts of water fall from the clouds. This lasts but a short time, and before one retires at night the sky is again clear and the stars remarkably brilliant. These thunderstorm phenomena gradually increase in daily duration and intensity, extending especially into the night, until the time of maximum rainfall, in June. At that time it may begin to rain early in the afternoon and continue nearly all night. The thunder-

storms then decrease to the *veranillo*, at which time they may cease entirely for a few days or weeks. They begin again after it and reach a second maximum in October, when they gradually decrease until December. The rainfall phenomena, though short and intense, are very local in area and have marked limitations in time. Their intensity is largely a question of topography and wind. Hence the most marked and striking variations exist, similar to those of local storms elsewhere, but more marked in character. Hence also marked localization of rainfall. A few rods will sometimes make one pass from within a torrential rain to a spot without rain. Hence also remarkable variations in the rainfall from year to year or in the same month of successive years or in the monthly rainfall at adjacent stations.

3. *The Annual Rainfall.*—The observations on which we have to rely are rarely synchronous, and consist chiefly of a few years' observations at each station, but scattered at the various stations through half a century. This makes it necessary to compare the longer series and see if there is any periodicity to be found of such character as to render it necessary to adjust the observations to the same date. Such a comparison is given in Table II for the ten or (combining Panama, Naos, and Taboga) eight best series, and a succession of maxima and minima at once appear, the ratio between the two being 4 to 7, 5 to 9, and even greater in some cases. It appears that the times of maxima are practically the same throughout Central America, and are as follows:

Maximum.	Interval of years.
1856	—
1861	5
1866–'7	5½
1872	5½
1878–'9	5½
1886–'7	8
1893	6½

These show a fairly regular periodicity of 5 to 8 years, not regular enough to justify discussion in such a fragmentary series of observations, but regular and large enough to

require adjustment if we are to have amounts for which comparisons are significant. I have therefore adjusted the actual annual values to get comparable means, using both the periods and a well known and safe principle of meteorological interpolation, which runs as follows: "In the long run the meteorological elements of neighboring stations vary together and in much the same ratio."

To piece out my statistics I have further interpolated annual values when I had less than twelve but more than eight months' of observations. In the case of Punta Gorda, in British Honduras, I have gone so far as to make an annual mean based on two months' observations, an inspection of the place, and common report. For instance, about Lake Izabal, at sealevel and not far from Punta Gorda, the common saying is that it rains thirteen months out of every twelve. There is no doubt that the rainfall at the head of the Gulf of Honduras is very high, and the two months' observation available from Punta Gorda, compared with Belize, enabled me to guess how high with an approximation better than nothing.

The adjusted annual values appear in the second column of Table III and are entered on the chart for annual rainfall, Plate 1. Several interesting conclusions appear at once:

1. The rainfall is greater on the Atlantic than on the Pacific side as two or three to one.

2. The greatest annual rainfall observed is at Greytown, Nicaragua, where it reaches the enormous total of over twenty feet—a figure surpassed in America only on the Mexican Gulf coast, in the West Indies, Guiana, and on the coast of Brazil.

3. The next greatest is in Alta Verapaz, on the northern slopes of mountains, and on the adjoining southern part of British Honduras. Next to this comes the east coast of Panama.

4. The region of smallest rainfall is along upper plateaus in most of Central America proper, but moving to the southern coast in the Isthmus region. The area sketched on the

map as below fifty inches of annual rainfall is based on the rainfall observed at Salamá, in Baja Verapaz; on the statement quoted by Reclus from Dollfuss and Mont Serrat for the *altos* or high plains in northwestern Guatemala, the region from which the streams radiate; on the common statement in that region that the upper part of the Motagua basin is the most arid part of Guatemala; and on statements of Squier, especially his estimate of forty eight inches for the upper part of Honduras. This region occupies the higher plateaus, but appears to extend farther down on the Pacific versant than on the Atlantic. I have terminated it near the Nicaraguan border simply because I have no evidence to take me further. It reappears in Costa Rica, at Agua Caliente, and then apparently passes over into the Gulf of Panama.

To account for this distribution of rainfall we have the following causes of rain: The equatorial rainbelt which accompanies the sun in his annual journeys north and south, and gives rain at the station when he is in the zenith; the trade winds, which are here northeast and which since leaving the West Indies have traversed the warm Caribbean sea; the rains which come down on winds from the north after crossing the warm Gulf of Mexico; and the cyclonic rains, which accompany the great atmospheric disturbances occuring at certain seasons in the West Indies. Calling the first the *invierno* rain, the second the trade rain, the third the norther rain, and the fourth the cyclonic rain, we have:

On the Pacific coast, *invierno* alone.

South of the Gulf of Campeachy and north of the mountain ranges,

Invierno + norther,

or more easterly,

Invierno + cyclonic.

From Cape Gracias á Dios southward,

Invierno + trade,

and possibly for its northern part also

+ cyclonic.

That the cyclones reach at times to the Bay of Honduras is known by the fact that they have at least twice devastated Roatan. In Belize people are accustomed to say that the hurricane winds do not reach them, but the accompanying rain and sea do, and, as a matter of history, there appears to be no record of injury in Belize by hurricane winds. The cyclones are certainly felt to the north of Cape Gracias á Dios. How much farther south this influence extends is not so clear. The character of the rainfall and the barometric variations would indicate that they occasionally affect the Mosquito Coast, and a slight barometric variation here means a heavy response in rainfall.

The northers give a heavy autumn and early winter rainfall in Alta Verapaz, according to the testimony and observations of Dr. Sapper. This rainfall comes with characteristics of our northern general rains. The sky is continuously cloudy, the rain is steady and lasts several days. On the north coast of Spanish Honduras the northers are well known, but here a distinction is made between dry northers and wet ones; the former are more easterly and bring charming dry weather; the latter bring heavy rains. Still farther south, but now on the plateaus, as far south as Rivas and even to the Gulf of Panama, perhaps once or twice a year at Rivas and once in two or three years at San José, there occurs a week or so in autumn which is called *temporal*. During this time the sky is continuously cloudy, the air is chill, the wind is northerly, and it fogs or mists or gently rains. The native, with his love of warmth and brightness, has a horror of the *temporal*. It appears, therefore, that the northers may reach far south on the plateau, though they drop the most of their rain on the northern mountains and coasts.

An interesting fact to be deduced from the observations is the variation of the rainfall with elevation. Taking the Alta Verapaz stations with a full year's record, we have:

Station.	Elevation.	Rainfall.
	Feet.	*Inches.*
Cubilguitz	984	167
Setal	2,395	202
Chiacam	2,789	222
Senahu	3,248	170
Panzamala	4,100	150
Chimax	4,285	98

In this case we have a maximum at about 2,500 feet of elevation—the decrease below due perhaps to sheltering mountains to the north. These winds, as was to be expected, are of very considerable depth or force and carry rain up to heights of 4,000 or 5,000 feet.

On the east coast the stations are at sealevel, and we have no opportunity to test the effect of elevation except at Colon and Gamboa. In the investigations for the Nicaragua canal, however, observations were taken in the San Juan valley by the engineers from April to September, 1851. Reducing these by means of Rivas to the later years, and then expanding by comparison of the months with those at Greytown, we get an annual rainfall of about 120 inches. The region occupied by the surveying party was well down the San Juan river, at a height certainly less than 100 feet (Lake Nicaragua, 130 feet). From this it appears that the trade which brings such enormous rains at Greytown is lessened in effect by a half or more in an ascent of less than 100 feet. Facts of the same character appear at Colon and Gamboa. The latter is on the watershed, and the instrument was 102 feet above sealevel. The rainfall at the former is a third larger than at the latter. If we consider that only a part of this rain is of trade origin, and that, as is to be shown, the *invierno* is little affected at elevations below 3,000 or 4,000 feet, we may conclude that the rain bearing stratum of the trades here is very shallow, and that most of its rain is dropped at elevations less than 500 feet.

Turning now to the lower central plateaus and the Pacific versant, where we have the typical *invierno*, we find:

Station.	Elevation.	Rainfall.	
	Feet.	*Inches.*	
Corinto	Sealevel	90	
Rivas	200	65	60±
Granada	218	52	
San Salvador	2,156	72	
San José	3,724	68	64±
Tres Rios	4,265	60	
Guatemala	4,856	54	

Here the interpretation is not simple, but it is safe to conclude that up to 4,000 feet there is very little variation with height, and that the variation with topography [{Rivas, Granada} or {San José, Tres Rios}] is much more important than that with the elevation. There is some indication of a maximum at 2,000 to 2,500 feet, as in Alta Verapaz.

4. *Distribution through the Year.*—If we examine the distribution of rainfall and of rainy days we find that there are four fairly distinct types, as shown by Table IV and Plates 2 and 3.

I. A type with typical *invierno* occupying the plateaus of moderate elevation and the Pacific versant from the north to southern Costa Rica and probably to the Gulf of Panama. It is characterized by maximum rainfall in June and in October, by almost no rainfall from November to April (the *verano*), and by a secondary minimum in August. The last is the *veranillo*, already referred to, and often consists of an almost complete cessation of rain for a week or fortnight. Comparing the curves of amounts of rain with that of the number of rainy days in the diagram, we find that what little rainfall comes in the *verano* is scattered through a relatively large number of days and is therefore very light, while that of the maxima (June and October) is scattered through relatively few days and is consequently heavy. This is

especially and remarkably true for October, when what rain falls is very heavy.

The succession of the seasons on the more southern coasts in this region are thus described by Findlay in his Directory of the North Pacific:

On the coast during the fine season, which commences in November and ends in May, the land and sea breezes blow alternately, with a clear sky and but little rain. Strong winds rarely occur during this period. * * * Occasionally a strong breeze from the northward may be experienced.

In the rainy reason, May to November, heavy rains, calms, light variable breezes, with a close, sultry atmosphere, heavy squalls, with thunder and lightning, and not unfrequently strong gales from the southwest, are prevalent.

During the fine season the land and sea breezes set in regularly; the former are called *el Terral* and the latter *la Virazon*. The only winds to be guarded against at this season are the northers [more properly the Papagayos]. These violent gusts give no warning but the noise created by them a few moments before they burst. Sometimes a thick fog sets in beforehand, which is dissipated at the first gust. These gusts are more frequent near the Gulf of Tehuantepec or abreast of the Gulf of Papagayos.

In the rainy season calms are frequent and the sea and land breezes which are felt on fine days have no regularity. The prevalent winds then are from southeast to southwest, blowing strongly and in squalls, bringing bad weather and torrents of rain for twelve or fourteen days in succession. During this season, nearly every afternoon about 3 or 4 o'clock a violent gust sets in from the northeast and lasts until daylight. These gales are called *chubascas*, and resemble the tornadoes of the African coast.

On the Mexican and Guatemalan coasts the *invierno* rains often come on strong, squally winds from the southwest, called *Cordonazo de San Francisco* (Castigation of St. Francis), and suspected of being occasional extensions of the southern trade winds. They occur from July to October.

It may be noted that throughout the region of Type I an idea is prevalent that the rainfall is decreasing and that this decrease is due to the rapid deforesting of the country. This idea is not justified by Table II, which gives the annual rainfall for the years, and its basis is probably to be found in the marked periodicity already pointed out.

II. The second type is in the northeast and has the *invierno* extended to January, with maxima in June and October, as in No. 1. The *verano* is encroached upon; there is no absolutely dry month, but April is the driest; and the *verano* rainfalls are relatively light. The *veranillo* is well marked and the rainfall in June and October is very heavy when it does fall—that is, its intensity or density is great.

As to details for Alta Verapaz, which are of great interest and have only recently become known, the following account is condensed from the statements of Dr. Sapper in the last three volumes of the *Meteorologische Zeitschrift.*

The chief climatic peculiarity of this northern slope is the occurrence of winter rains (October to January) in addition to the usual *invierno.* In the winter rainfall season electric phenomena are unusual, and for a month or two completely fail; moreover, the rain when it comes is gentler than in summer, shows no distinct diurnal period as it does in the summer season, and may last several days. In short, it shows rather the character of the general storms of the temperate latitudes, while the summer season rainfalls are more of the nature of our local storms. During these winter rains stratus is the characteristic cloud form, the sky is often clouded continuously for days, and a light rainfall may continue with slight interruptions from day to day. The wind is higher than in the summer rains and the temperature is cool.

From February to April in Alta Verapaz the weather is relatively dry; both the number of days of rain and the rainfall of each are relatively small. In autumn the summer and winter rains are sometimes separated from each other by a short dry period. Sometimes the former passes into the latter without an interruption of the rains. In 1889 such a dry season occurred, but in 1890 it was not distinguishable. The two zenithal maxima of thunderstorm frequency can usually be distinguished and the first is the greater. In general the changes of the barometer are here small, the wind is generally light, moving east and west on

account of the topography, but the cirrus clouds usually pass north and south.

As there are no observations for Spanish Honduras, its division between Types II and III must be justified. This has already been done for its part of Type I.

The only thing like observations on rainfall in the Republic of Honduras are those of Thomas Young at the mouth of Rio Negro (latitude 16° north, longitude 85° west) about 1840 and quoted by Squier,* and from this author practically all the notes which follow are taken.

According to Young's notes, March to June was dry, with northeasterly winds and sea breezes; July was wet, with strong sea breezes; August to September was dry, with calms and light variable airs; October dry or wet, according to the wind, and November to February were wet, with northers. Thus the dry season here extends from March to September, July only being wet in these eight months. The wet season is the four months from November to February, with sometimes October. A residence of a few weeks at Puerto Cortez and the reports given me there would indicate about the same course of the seasons, but July and August were wet.

The northers to which reference is here made are thus described in Henderson's "Honduras:"

> At the beginning of October, what are called the *norths* commence and generally continue, with little variation, till the return of February or March. While these winds last the mornings and evenings are cold, frequently unpleasantly so; and what in this country is understood by a *wet north* might perhaps furnish no very imperfect idea of a November day in England. A *dry north*, on the contrary, is beautiful, agreeable, and invigorating.

At Truxillo rains occur in June and July; at Santa Tomas, at the extreme west of the north coast of Honduras, they have much rain, with a climate as at Punta Gorda, not far distant. In general, along the north coast from Santa Tomas

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*Squier (E. G.), The States of Central America. 8°. New York, 1858, pp. 25-43; *also* Squier (E. G.), Honduras. 8°. London, 1870. The latter is little more than a reprint of that part of the former which relates to Honduras.

to Cape Gracias á Dios, the wet northers occur in the winter months and bring rain.

Passing inland to the mahogany districts, and therefore at no great elevation and not far from the coast, the *invierno* proper resumes sway and heavy rains begin in the latter part of May or in June. The mahogany cutters must "truck" their logs to the river in the dry, to float them in the wet season, and they must not be left exposed long without covering or they will "check."

Squier says (*op. cit.*, p. 197): "In the months of April and May, all the various preparations having been completed and the dry season having become sufficiently advanced, the 'trucking' commences in earnest. This may be said to be the mahogany cutters' harvest, as the result of his season's work depends upon a continuance of the dry weather, for a single shower of rain would materially injure his roads."

And again, as to the floating, he says (p. 198): "About the end of May the periodical rains again commence. The torrents of water discharged from the clouds are so great as to render the roads impassable in the course of a few hours, when all trucking ceases; the cattle are turned into the pasture and the trucks, gear, and tools, etc., are housed. The rain now pours down incessantly till about the middle of June, when the rivers swell to an immense height. The logs then float down a distance of 200 miles, being followed by the gangs in pitpans (a kind of flat-bottomed canoe) to disengage them from the branches of the overhanging trees, until they are stopped by a boom placed in some situation convenient to the mouth of the river."

At Comayagua, inland and about half way between the Atlantic and Pacific coasts, rain falls every month in the year, but in the dry season of the western versant this rain is only in showers of brief duration, while during the wet season of that coast the Comayagua rains are long and many. Continuous rains or *temporales* are infrequent. Snow sometimes falls on the high plains of Inticubat, but only in thin layers, which soon disappear. In my own observations the evi-

dences of heavy rainfall rapidly disappeared as one ascended to the interior plateaus, where the population is chiefly gathered.

III. The third type has well marked summer, autumn, and winter rains, with three distinct maxima both in amount and intensity, viz., July, November, and January. There is no really dry month, but March is the driest. The *veranillo* is characterized by slight intensity rather than by absence of rainfall, and the intensity is greatest in the winter rains.

At Greytown, says one of the reports on the Nicaragua canal, "the rainy season ends in January with a norther, which is usually the worst gale at this port. The dry season then lasts until in May, when the rains set in. The beginning of the rains shift from the first of May to the first of June, but is usually late in May. In the latter part of August and in September there is pleasant, serene weather, with less rain, but in October again set in the daily rains, with disagreeable weather. The only regular winds found at this place are the trade winds, which, however, do not blow constantly. They vary from east by north to northeast, generally at east-northeast, are not strong, and rarely last all night, being succeeded about 10 p. m. by light and baffling land breezes, varying between south-southeast and northwest. This place seems to be near the limit of the trades, so they cannot be depended on, though they usually blow every day, but sometimes very light and only for a few hours. Along the coast to the southward still less dependence can be placed on them, while at Monkey Point, 40 miles to the northward, they are stronger and more reliable."

In the San Juan valley, between Greytown and Lake Nicaragua, there is a record of six months (April to September) in 1851. They show that the rainfall decreases as the river is ascended and give less than one half as much as at Greytown, and Menocal in 1885 * estimated the annual rainfall of the whole basin at more than 100 inches. Dr. Brans-

* Nic. Canal Route Report. 49th Cong., 1st session, Sen. Ex. Doc. No. 99, 1886, p. 37.

ford also says: * "The rainfall diminishes as we ascend the River San Juan, and after passing the mouth of the San Carlos the weather is bright and pleasant in the dry season, vegetation is not so rank, the land is well adapted to agriculture, and, as it is sufficiently damp for the growth of grass, cattle raising is an easy and lucrative business."

IV. The fourth type is one of transition. It is one in which the zenithal maxima of the *invierno* of higher latitudes are separating from each other in preparation for change into the opposite months of the year south of the meteorologic equator. The *verano* is well marked but brief—January, February, and March. The maxima are in April and November, and the summer dry season is here extended, but only relatively dry, while there is a brief drier season. There is also a season at the end of June when the rains are altogether suspended, but this is too brief to be noticeable on the diagram. This is the *veranito* or *verano* of St. John.

The succession of the seasons is given by the Hydrographic Office in their Coast Pilot: †

> The wet season commences in May and lasts till November. The rainfall gradually increases until it is fairly established in June, and continues through July, August, and September, with strong southerly winds. In December the rains cease, the northwest and north-northwest winds set in, producing an immediate change. During the dry season regular land and sea breezes blow. The sea breeze sets in about 10:30 a. m. from south-southwest, and generally increases in force until about 3:30 p. m., after which it gradually subsides and at sundown is quite calm.

5. *Distribution through the Day at San José, Costa Rica.*—The rainfall of the *invierno* has a marked diurnal periodicity; with the trade-wind rainfall this periodicity is less marked, and with the rain from cyclonic sources or from northers the diurnal variation is nearly suppressed. The diurnal features are, therefore, best marked in the region of typical *invierno*, and, as a matter of fact, the observations

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* 43d Cong., 1st session, Sen. Ex. Doc. No. 57, 1874, p. 114.

† Publication No. 84. West Coast of Mexico and Central America, etc. 8°. 2d edition, 1893, p. 238.

published permit us to study its details only at San José, which is in this region and is, moreover, quite free from non-periodic disturbances of the barometer, and therefore from cyclonic action. The hourly observations available were for the three years 1889, 1890, and 1891. The combination of these observations by hours and months is given in Table VIII and represented graphically on Plate 4, where the hours (two by two) are represented by the horizontal lines, and the months by the vertical lines, the annual rainfall for the hour in that month in inches being placed at the intersection of these lines. The culmination of the rainfall at from 4 to 6 in September and October is very manifest. In October more than half the rain falls in the three hours from 3 to 6 p. m., and two-thirds in the five hours from 1 to 6 p. m. A similar statement may be made for the months, viz., at 4 p. m. more than half the rain falls in August, September, and October. In January the little rainfall is in the morning hours, but generally speaking the rain does not begin here until noon, nor fall after 10 p. m., so that practically all the rainfall is confined to the afternoon hours and nearly all to the five hours from 1 p. m. to 6 p. m.

The same order of facts is shown in the number of hours of rainfall for each month of the year, for the calculation of which observations are available at San José for ten years. The results are:

January	8	hours per year.
February	1	hour " "
March	8	hours " "
April	16	" " "
May	74	" " "
June	66	" " "
July	65	" " "
August	89	" " "
September	77	" " "
October	94	" " "
November	34	" " "
December	18	" " "
Total	550	" " "

6. *Variations of Rainfall.*—The periodic variations have already been noted. The values for different years may vary as 2 to 1 or even as 3 to 1 (see columns 5 and 8, Table III, p. 24.) The monthly variations are still greater, and are greatest for the months following the dry season, especially May. This means only that the *invierno* begins earlier some years than others, and the date of its commencement may vary a full month.

Of yet greater interest are the maximum daily rainfalls (see column 7, Table III, p. 24), and these are most significant when given as percentages of the total annual rainfall.

Maximum Daily Rainfall.

Station.	Month.	Inches.	Percentage of annual rainfall.
Guatemala	August	3.88	7.2
Alta Verapaz (Setal)	November	9.58 (212)	4.5
Salamá	June	3.39	12.1
San Salvador	October	2.38	3.3
Rivas	October	4.58	7.0
San José	July	5.04	7.4
Tres Rios	October	3.43	5.7
Colon	May	5.17	4.2
Gamboa	August	6.23	6.6
Panama	August	6.42	13.1

Of the 9.58 inches at Setal, 7.12 inches fell during the night.

The absolute maxima of rainfall can be obtained only from long series of observations, and these series are generally short. It is therefore safe to say that from 7 to 10 per cent of the total annual rainfall may descend in one day in Central America, and that for the drier *invierno* region this percentage may reach from 10 to 15 per cent.

This sounds extraordinary, and certainly the fall of from 4 to 10 inches of rainfall in one day, and usually in a few hours, gives one a striking idea of how the rain descends in

tropical regions. It is sometimes not a rain, but a celestial cataract.

At San José we are able to get some idea of the maximum rainfall per hour during the three years of hourly observations available. It is, of course, an afternoon hour, and is noteworthy only from May to October, when the maxima actually observed had the following values:

May	1.90 inches.
June	1.02 "
July	1.36 "
August	1.13 "
September	1.15 "
October	1.39 "

That is, the greatest hourly rainfall observed at San José was 1.9 inches, or a rate of 46 inches, nearly 4 feet, per day.

The results of such enormous falls of rain have often been described and can easily be imagined. The dry stream beds or *quebradas*, very common on the plateaus, are rapidly filled; the water comes down in a wall several feet high; the camping place, 2 to 6 feet above the water, is overflowed, and soon the new camping place, hastily sought in the dark and several feet higher, is also overflowed. In such a country as Mosquitia dry stream beds become rivers, marshes change to lakes, and the natives temporarily take to the trees or to their boats.

While all this is striking, it is by no means unparalleled in temperate regions. Symons records an English rainfall of 6.8 inches in one day; 7.5 inches in a day is no great rarity in the United States, while the Gulf and Atlantic coasts are subject to occasional falls of 10 inches in one day, and Boisé, Idaho, once reported 18 inches. At Joyeuse,* in the Rhone valley, 29.3 inches were recorded in one day in October, 1827, and at Gibraltar* November, 1826, 30.9 inches are said to have fallen in that time. The difference between such falls of rain in the tropics and in the temperate zones is chiefly that in the latter they are occasional, while in the

* Wagner, *op. cit.*, p. 16.

tropics they are customary. These conditions are especially interesting from the standpoint of the possible ship canals in Central America. Though the information is scanty, it appears to have been such a rainfall in 1887 which began the disasters of the Panama canal. It must be acknowledged that the conditions at Suez, Sault Ste. Marie, and the Welland canal are in this respect very favorable, for with them the question of sudden floods does not enter. It enters in the case of the great ship canal of St. Petersburg-Cronstadt and of those of the Ganges-Brahmaputra delta, but in these cases there are no changes of level sufficient to make the use of locks necessary. Indeed, the use of locks on ship canals whose feeders are subject to sudden and violent floods appears to present a new engineering problem, first met in the Panama canal.

NOTE.—Since reading this paper my attention has been called to two remarkable daily rainfalls recorded in *Nature*, vol. xlviii, pp. 3 and 77.

At Crohamhurst, Queensland, Australia, from 9 a. m. February 2 to 9 a. m. February 3, 1893, there fell 35.7 inches of rain. Crohamhurst is in latitude 26° 50′ south, longitude 152° 55′ east, and has an elevation of about 1,400 feet above the sea. The report was made by Mr. Clement L. Wragge, government meteorologist for the colony.

Mr. E. Douglas Archibald reports for Chirapunji, Khasia Hills, British India, on June 14, 1876, 40.8 inches of rain.

These are probably the highest daily rainfalls recorded.

TABLE I.

Stations.

Station.	State.	Latitude north.	Longitude west.	Altitude in feet.	Observations. Begun.	Observations. Ended.	Number of years.
Guatemala City	Guatemala	14° 38′	90° 31′	4,856	1856	1883	13½ yrs.
Chiacam	"	15° 50′	90° 15′	2,789	1890	1892	2 "
Chimax	"	15° 51′	90° 15′	4,285	1891	1892	2 "
Cubilguitz	"	....	....	984	1891	1892	20 mos.
Panzamala	"	....	....	4,100	1892	....	12 "
Samac	"	....	....	4,265	1892	....	6 "
Secoyote	"	....	....	3,806	1892	....	3 "
Senahu	"	....	....	3,248	1891	1892	16 "
Setal	"	....	....	2,395	1891	1892	13 "
Campur	"	15° 54′	90° 10′	2,789	1891	1892	8 "
Salamá	"	15° 15′	90° 25′	3,068	1891	1892	12 "
Belize	British Honduras.	17° 29′	88° 16′	sea level.	1848	1894	18 yrs.
Punta Gorda	"	16° 20′	88° 35′	"	1894	....	2 mos.
San Salvador	Salvador	13° 44′	89° 9′	2,156	1889	1892	40 "
Bluefields	Nicaragua	12° 0′	83° 43′	sea level.	1883	1886	32 "
Greytown	"	10° 59′	83° 42′	"	1890	1893	41 "
Rivas	"	11° 30′	85° 47′	200	1850	1893	16 yrs.
Granada	"	11° 56′	85° 54′	218	1883	1884	2 "
Virgin Bay	"	11° 25′	85° 47′	120	1872	1873	8 mos.
Corinto	"	12° 28′	87° 12′	sea level.	1850	1851	13 "
San José	Costa Rica	9° 56′	84° 8′	3,724	1866	1891	19 yrs.
Heredia	"	9° 59′	84° 9′	3,776	1865	1868	4 "
Tres Rios	"	9° 55′	84° 15′	4,265	1889	1890	22 mos.
Agua Caliente	"	9° 50′	83° 57′	4,364	1889	1890	2 yrs.
Port Limon	"	10° 0′	83° 3	sea level.	1865	1866	11 mos.
Colon	Colombia	9° 22′	79° 55′	"	1862	1888	19 yrs.
Gamboa	"	9° 10′	79° 43′	102	1881	1888	6 "
Naos	"	8° 57′	79° 31′	46	1881	1888	7 "
Taboga island	"	8° 48′	79° 32′	sea level.	1861	1866	4 "
Panama	"	8° 57′	79° 32′	"	1879	1882	4 "
Napipi river	"	6° 38′	78° 13′	100	1875	....	2 mos.

TABLE II.

Annual Rainfall at Principal Stations in Inches.

Year.	Guatemala.	Belize.	San Salvador.	Rivas.	San José.	Colon.	Gamboa.	Naos.	Panama.	Taboga island.
1848..	......	47.2	......	......	......	......	......	......	......	.....
1856..	63.0	......	......	......	......	......	......	......	......	.....
1857..	54.5	......	......	......	......	......	......	......	......	.....
1858..	50.2	......	......	......	......	......	......	......	......	.....
1859..	59.3	......	......	......	......	......	......	......	......	.....
1860..	48.3	......	......	......	......	......	......	......	......	.....
1861..	71.7	......	......	......	......	......	......	......	......	71.9
1862..	48.0	......	......	......	......	......	......	......	......	48.5
1863..	42.7	53.2	......	......	......	109.4*	......	......	......	45.2
1864..	49.8	78.8	......	......	......	115.7*	......	......	......	30.2
1865..	......	75.3	......	......	......	107.4	......	......	......	.....
1866..	......	67.9	......	......	63.4	129.6	......	......	......	.....
1867..	......	88.9	......	......	73.5	121.6*	......	......	......	.....
1868..	......	59.8	......	......	56.1	120.4	......	......	......	.....
1869..	......	86.3	......	......	62.9	114.2	......	......	......	.....
1870..	......	......	......	......	75.1	149.6	......	......	......	.....
1871..	......	......	......	......	75.6	99.6	......	......	......	.....
1872..	......	......	......	......	86.8	170.2	......	......	......	.....
1873..	......	......	......	......	55.8	87.1	......	......	......	.....
1874..	......	......	......	......	60.8	137.7	......	......	......	.....
1875..	......	......	......	......	59.8	......	......	......	......	.....
1876..	......	......	......	......	50.4	......	......	......	......	.....
1877..	......	......	......	......	53.4	......	......	......	......	.....
1878..	......	105.3	......	......	60.3	......	......	......	......	.....
1879..	60.6*	91.3	......	......	86.4	......	......	......	84.7	.....
1880..	49.4	77.6	......	64.4	61.5	......	......	......	66.3	.....
1881..	55.2	91.3	......	79.2	......	103.0*	......	......	70.5	.....
1882..	49.5	63.0	......	61.3	......	124.1	69.0	29.5	45.6	.....
1883..	......	79.4	......	49.8	......	111.7	......	37.2	......	.....
1884..	......	......	......	54.7	......	104.5	90.6	41.8	......	.....
1885..	......	89.0	......	34.5	......	146.3	97.6	42.6	......	.....
1886..	......	69.3	......	87.2	......	137.2	103.0	69.9	......	.....
1887..	......	100.2	......	74.9	......	159.7*	127.4*	51.0*	......	.....
1888..	......	72.2	......	55.5	59.2	......	......	......	......	.....
1889..	......	......	106.5	84.4	85.2	......	......	......	......	.....
1890..	......	......	......	31.8	71.8	......	......	......	......	.....
1891..	......	......	34.4	66.0	65.2	......	......	......	......	.....
1892..	......	......	73.6	78.3	......	......	......	......	......	.....
1893..	......	......	......	105.1	......	......	......	......	......	.....
1894..	......	......	......	47.3	......	......	......	......	......	.....

—— Refers to maximum.

* refers to interpolations. No interpolations made for less than nine months of a year.

TABLE III.

Annual Means (adjusted) and Other Annual Values in Inches.

Station.	Annual.	No. of days of rain.	Intensity per day.	Maximum.			Min. in any year.	Days of more than one mm. rain.	Thunderstorm, days.
				One year.	One month.	One day.			
Guatemala City	54	145	0.37	72	16	3.88	43	.....	87
Alta Verapaz (9 stations)	155	204	0.76	222	100	9.58	87	158	61
Salamá	28	85	0.33	.....	10	3.39	.....	63	.....
Belize	79	.....	......	105	22	7.40	47	.....	.....
Punta Gorda	184	.....	......	.....	.....	......	.....	.....	.....
San Salvador	72	139	0.52	106	38	2.38	34	.....	66
Bluefields	100	223	0.45	.....	20	......	.....	.....	.....
Greytown	260	.....	......	297	53	......	214	.....	.....
Rivas	65	120	0.54	105	25	4.58	32	.....	.....
Granada	52	.....	......	.....	20	......	.....	.....	.....
Virgin Bay	66	.....	......	.....	.....	......	.....	.....	.....
Corinto	90	.....	......	.....	23	.....	.....	.....	.....
San José	68	188	0.36	87	20	5.04	50	130	31
Heredia	65	159	0.41	.....	.....	......	.....	.....	.....
Tres Rios	60	94	......	.....	23	3.43	.....	94	.....
Agua Caliente	48	171	0.28	.....	14	2.22	.....	149	.....
Port Limon	89	.....	......	.....	23	......	.....	.....	.....
Colon	122	217	0.56	152	32	5.17	87	172	.....
Gamboa	95	165	0.58	127	24	6.23	69	155	.....
Panama	49	125	0.39	72	20	6.42*	29	103	.....

* Wagner, *op. cit.*, p. 16.

TABLE IV.

MONTHLY RAINFALLS.

I.—*Typical Invierno; Maxima in Spring or Early Summer and in Early Autumn: Veranillo Brief.*

	Guatemala City.	Salamá.	San Salvador.	San Juan valley.	Rivas.	Granada.	Virgin bay.	Corinto.	San José.	Heredia.	Tres Rios.
January	0.4	0.0	0.0	....	0.4	0.1	0.4	0.4	0.8	0.3	0.0
February	0.2	0.0	0.1	....	0.1	0.0	0.3	0.0	0.2	0.0	0.0
March	0.6	0.0	1.0	....	0.2	0.0	....	1.4	1 0	0.8	1.0*
April	1.7	0.0	2.8	0.4	0.3	0 1	....	0.4	1.7	2.2	2.7
May	4.8	4.4	8.0	9.1	7.5	0.2	....	9.1	8.5	8 9	14.4
June	11.0	10 5	12 0	14.2	11.1	6.7	....	14.2	8 4	8.7	8.7
July	8 7	3.7	19 5	22.6	7.5	3.3	4.9	22.6	8 3	5.7	4.2
August	9.1	2.6	11.8	11.8	8.1	4.6	8.9	11.8	8.9	5 4	13.0
September	9.4	4.5	10.9	13.2	9.4	9.3	11.0	10.1	11.9	9.1	10.8
October	9.0	0.4	6.5	....	16.9	14.2	12.1	17.9	11.1	14.2	12 6
November	0 8	1.2	2.9	....	3.9	3.0	8.8	1.4	4.5	4.1	2.1
December	0.3	0.0	9.7	....	1.5	0.1	1.4	3.2	1.2	1.6	0.0
Annual	56.0	27.3	70.2	....	64.9	41.6	....	92.5	66.5	61.2	69.5

II.—*Rainfall Throughout the Year; Maxima in Early Summer and in Autumn.*

	Chiacam.	Chimax.	Cubilguitz.	Panzamala.	Samac.	Secoyote.	Senahu.	Setal.	Campur.	Belize.	Punta Gorda.
January	4.4	4.9	11.4	6.7	....	....	3.7	17.3	8.7	5.9	....
February	5.5	4.0	5.9	4.3	....	....	2.5	10.2	4.4	3.0	....
March	3.2	4.6	4.6*	2.4	....	....	3.0	13.6	8.6	1.6	....
April	1.2	2.5	3.2*	0.6	....	....	2.4	1.8*	0.9	2.0	....
May	8.5	6.3	8.9	18.1	....	25.0	27.0	8.0	12.8	1.6	....
June	101.0*	14.1	16.0	22.2	....	19.9	26.5	28.7	23.9	6.3	....
July	19.0	13.2	22.1	27.9	12.3	38.1	36.5	21.7	27.6	6.3	....
August	14.7	7.0	11.8	15 3	8.1	....	20.3	13.9	....	6.8	26.9
September	25.9	10.6	18.1	10.6	11.5	....	19.0	20.0	....	6.6	12 2
October	18.0	11.8	17.5	19 8	27.8	....	13.3	25 0	....	13.5	....
November	13.8	11.8	23 5	16.4	17.5	....	10.5	27.9	....	8 2	....
December	3 8	6.0	14.0	6.1	2.8	....	5.1	14.3	8.8	7.1	....
Annual	221.7*	96.8	157.0*	150.4	....	....	169.8	202.4*	....	68.9	....

—— Refers to maximum. * Interpolated values.

TABLE IV (Continued).

III.—*Rainfall Throughout the Year; Maxima in Late Summer and in Winter.*

	Bluefields.	Greytown.	Agua Caliente.	Port Limon.
January	6.5	23.3	3.3	23.3
February	4.0	7.0	0.3	6.8
March	2.5	4.2	1.4	3.7
April	2.5	14.2	1.6	3.3
May	4.3	18.1	7.4	4.0
June	10.8	29.1	5.3	4.4
July	18.4	38.4	4.4	5.0
August	12.2	26.3	8.3	9.4
September	5.8	11.3	7.2	....
October	5.3	24.2	10.5	1.7
November	9.8	30.2	2.4	12.7
December	10.4	33.0	5.0	4.8
Annual	92.5	259.3	57.1	....

IV.—*Invierno in Transition to Southern Hemisphere; Maxima in Spring and Autumn; Veranillo Longer.*

	Colon.	Gamboa.	Panama.	Naos island.	Taboga island.
January	3.2	0.5	0.5	0.7	0.1
February	1.4	0.5	0.7	0.1	0.0
March	1.5	0.4	1.6	0.3	0.0
April	36.5	2.7	2.8	1.0	0.6
May	11.1	12.2	7.6	5.6	4.8
June	13.5	10.5	7.9	4.9	6.1
July	15.1	8.8	7.6	4.3	4.6
August	14.8	14.0	6.8	4.8	7.1
September	11.5	12.0	7.5	7.1	7.3
October	14.6	12.9	9.5	6.5	7.3
November	22.7	13.4	11.6	6.5	4.1
December	11.0	6.9	2.7	3.5	6.6
Annual	156.9	94.8	66.8	45.3	48.6

—— Refers to maximum.

Table V.

Days of Rainfall.

I.—Typical Invierno.

Station.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Guatemala City	4	3	3	5	15	23	20	21	22	18	7	4	145
Salamá	0	3	3	2	14	19	15	8	15	2	4	0	88
San Salvador	0	2	3	7	13	23	27	23	21	11	7	2	139
Rivas	4	3	0	1	8	17	13	15	19	22	12	6	120
San José	5	2	5	8	21	25	23	25	25	26	15	8	188
Heredia	1	1	2	8	18	21	22	18	24	23	14	7	159
Tres Rios	0	0	1	7	14	16	10	15	18	11	2	0	94

II.—Through the year.

Station.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Chiacam	20	11	11	10	15	20	21	21	25	20	18	16	208
Chimax	15	12	10	9	13	23	23	21	25	21	18	15	204
Cubilguitz	10	8	9	6	20	22	26	15	23	23	17	15	194
Panzamala	12	7	6	3	21	19	17	10	11	17	14	8	145
Senahu	8	6	13	8	24	27	28	26	28	24	18	21	229
Setal	17	12	14	3	15	27	28	24	28	27	15	13	223
Campur	[15]	13	11	8	22	25	21	26	27	22	24	21	*231

III.—Through the year.

Station.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Bluefields	18	10	13	14	12	25	31	25	33	18	22	12	223
Agua Caliente	15	4	5	10	13	18	18	18	19	20	12	19	171

IV.—Summer and winter rains.

Station.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Colon and Aspinwall	11	10	7	10	20	23	25	24	21	22	25	19	217
Gamboa	3	2	2	8	19	18	19	21	21	20	21	11	165
Naos island	4	1	1	5	13	13	12	15	15	17	17	12	125

Table VI.

Days of more than 1 *mm. of Rainfall.*

I.—Typical invierno.

Station.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Salamá	0	0	0	0	11	15	12	6	13	2	4	0	63
San José	2	2	0	2	16	20	13	22	23	18	8	4	130
Heredia	0	0	1	7	14	16	10	15	18	11	2	0	94

II.—Rainfall through the year.

Station.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Chimax	7	12	7	9	6	18	23	16	22	20	15	15	170

III.—Rainfall through the year.

Station.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Agua Caliente	15	3	4	8	13	17	17	18	16	19	9	10	149
Bluefields	17	4	2	10	13	18	18	16	16	17	12	17	160

IV.—Rainfall through the year.

Station.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Gamboa	3	3	2	7	17	17	17	19	18	20	20	12	155
Naos island	3	0	1	3	11	10	10	12	13	14	15	11	103

Table VII.

Maximum Rainfall in one Day.

I.—Typical Invierno.

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Max.
Guatemala City......	1.57	0.72	1.17	2.22	1.93	3.00	2.96	3.88	3.37	3.32	1.00	0.29	3.88
Rivas......................	1 36	0.33	0.07	0 67	4 09	3.40	2.71	3 98	2.83	4.58	3.15	1.21	4 58
San José..................	0.51	0.08	0 79	0,75	3.31	2.05	5,04	2.40	2.40	2.24	1.02	0.42	5.04
Tres Rios	0.0	0.0	1.02	1.22	3.31	1.77	1.18	1.69	1.38	3.43	1.57	0.0	3.43

II.—Rainfall throughout the year.

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Max.
Belize..	2.0	1.2	1.5	0.5	2.2	1.5	1.6	7.4	6 0	4.7	3 7	4.2	7.4
Setal.........................	....	....	....	....	....	....	....	....	....	....	....	....	9.6

III.—Rainfall throughout the year.

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Max.
Bluefields...............	2.4	1.2	1.0	0.7	1.0	1.5	3.4	1.6	1.4	0.6	1.3	1.4	3.4
Agua Caliente........	0.6	0.5	1.4	0.8	2.0	1.1	1.5	1.9	1.3	2.2	0.7	1.9	2.2

IV.—Rainfall summer and winter.

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Max.
Colon......................	1.2	1.8	0.6	4.5	4.1	3.3	4.2	5.6	3.2	4.7	6.2	3.8	6.2
Gamboa..................	1.0	0.5	0.4	2.8	3 8	5.5	3.2	6 2	3.2	5.4	4.0	3.4	6.2
Naos island	0.8	0.2	1.3	1.0	2.5	2.4	2 6	1.9	3.1	1.8	2.2	2.1	3.1

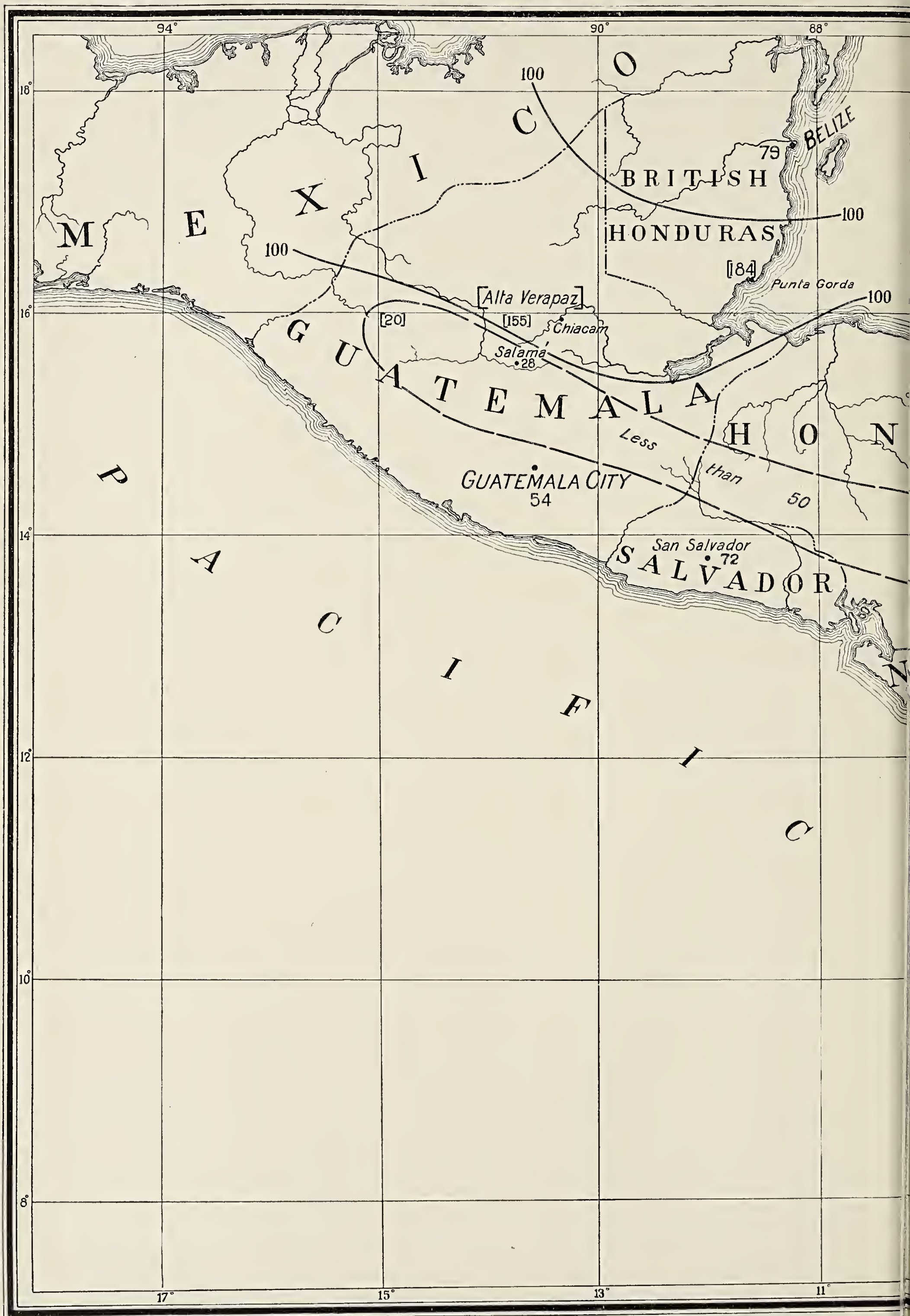
Table VIII.

AMOUNTS OF HOURLY RAINFALL.

Mean for three Years (1889–'91).

Station, San José, Costa Rica.

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Midnight to 1 a. m.	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.3	0.0	0.0
1 to 2 a. m.	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.3	0.0	0.1
2 to 3 "	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.4	0.0	0.0
3 to 4 "	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
4 to 5 "	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
5 to 6 "	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0
6 to 7 "	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0
7 to 8 "	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0
8 to 9 "	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0
9 to 10 "	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0
10 to 11 "	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.1	0.1	0.0	0.1
11 to 12 m.	0.0	0.0	0.0	0.1	0.0	0.1	0.5	0.3	0.2	0.2	0.0	0.1
Noon to 1 p. m.	0.0	0.0	0.0	0.2	0.0	0.5	0.7	0.5	0.7	0.3	0.2	0.1
1 to 2 p. m.	0.0	0.0	0.2	0.2	0.5	0.9	0.9	0.5	1.0	1.0	0.3	0.0
2 to 3 "	0.0	0.0	0.1	0.4	0.4	1.0	1.4	1.2	0.9	1.2	0.4	0.1
3 to 4 "	0.0	0.0	0.3	0.1	1.2	1.0	1.8	1.4	3.0	1.2	0.4	0.1
4 to 5 "	0.0	0.0	0.2	0.1	1.9	1.5	1.6	2.0	2.2	2.1	0.4	0.0
5 to 6 "	0.0	0.0	0.0	0.2	1.8	1.6	1.0	1.3	2.0	1.8	0.3	0.0
6 to 7 "	0.0	0.0	0.0	0.4	1.6	0.7	0.6	0.9	1.2	2.1	0.4	0.0
7 to 8 "	0.0	0.0	0.1	0.1	0.9	0.6	0.5	0.8	0.6	1.0	0.4	0.0
8 to 9 "	0.0	0.0	0.0	0.0	0.4	0.2	0.3	0.4	0.6	0.6	0.2	0.0
9 to 10 "	0.0	0.0	0.1	0.0	0.2	0.1	0.1	0.2	0.2	0.6	0.1	0.0
10 to 11 "	0.0	0.0	0.0	0.1	0.3	0.1	0.0	0.1	0.1	0.5	0.1	0.0
11 to midnight	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.1	0.0	0.4	0.0	0.0



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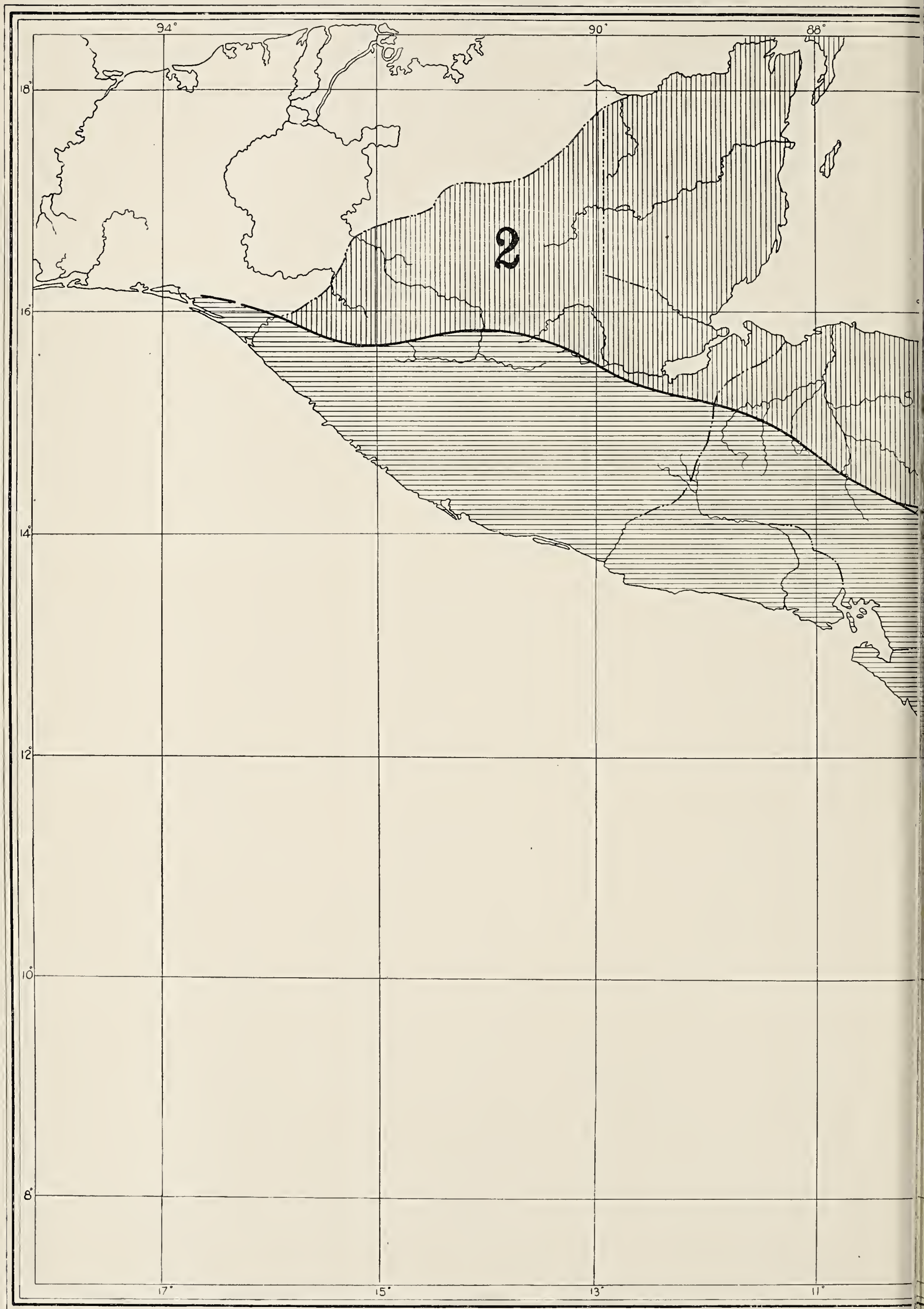
CENTRAL AMERICA.

ANNUAL ISOHYETALS OF CENTRAL AMERICA.



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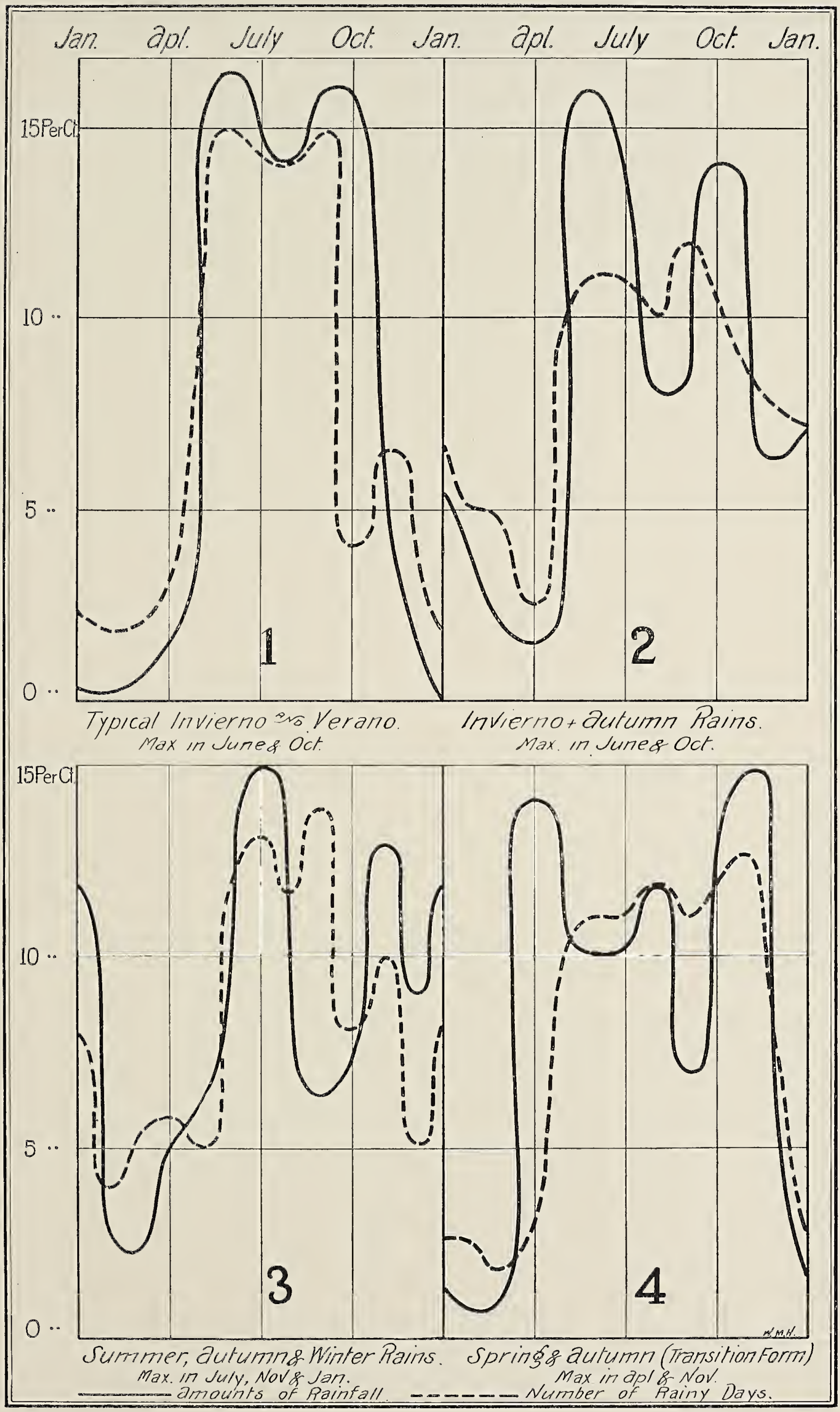
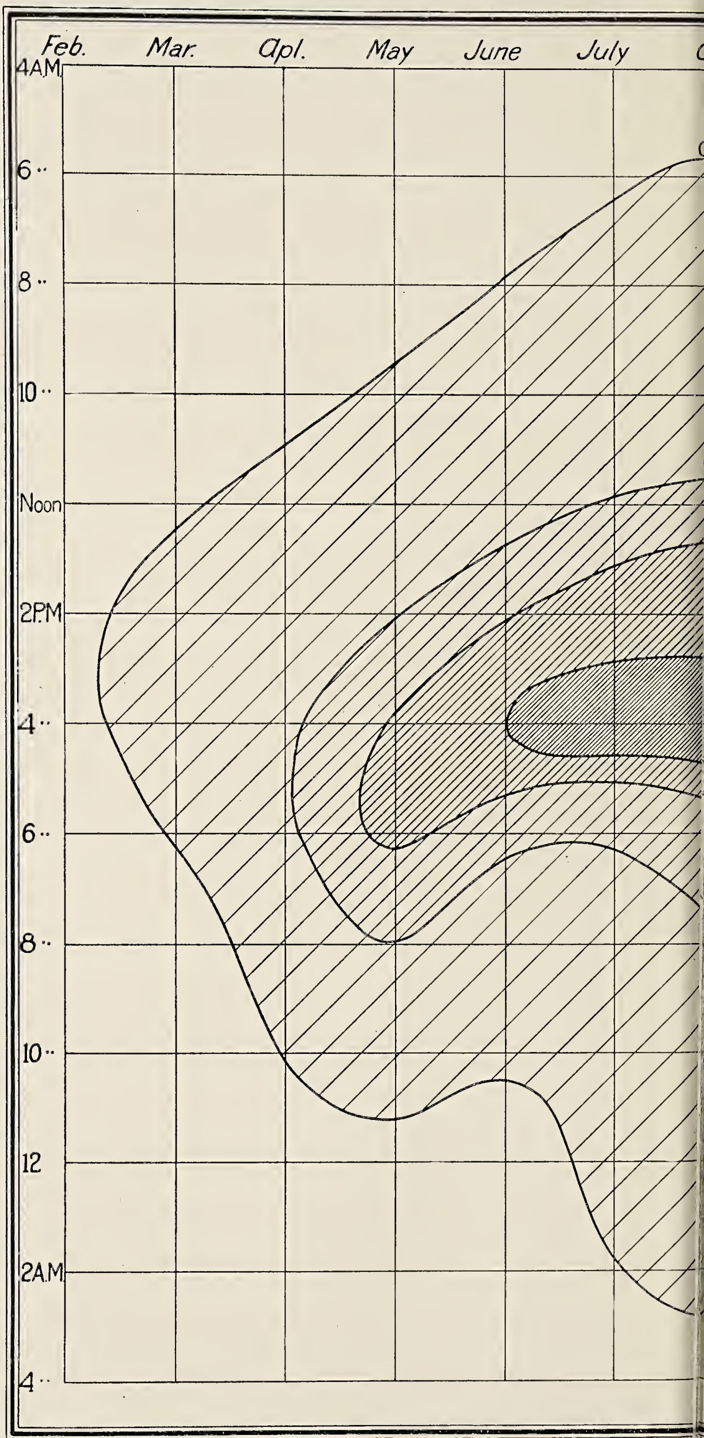
LL IN CENTRAL AMERICA.

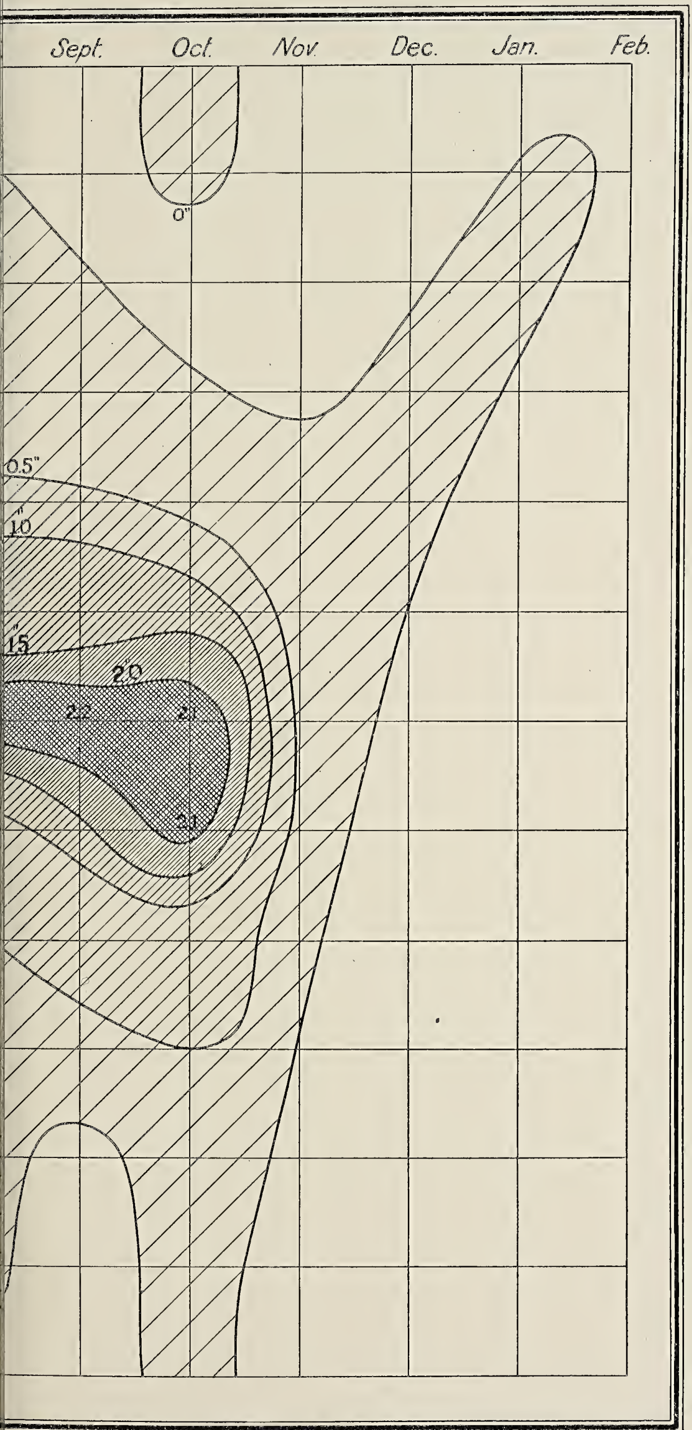
DISTRIBUTION OF TYPES OF RAINFALL IN CENTRAL AMERICA.



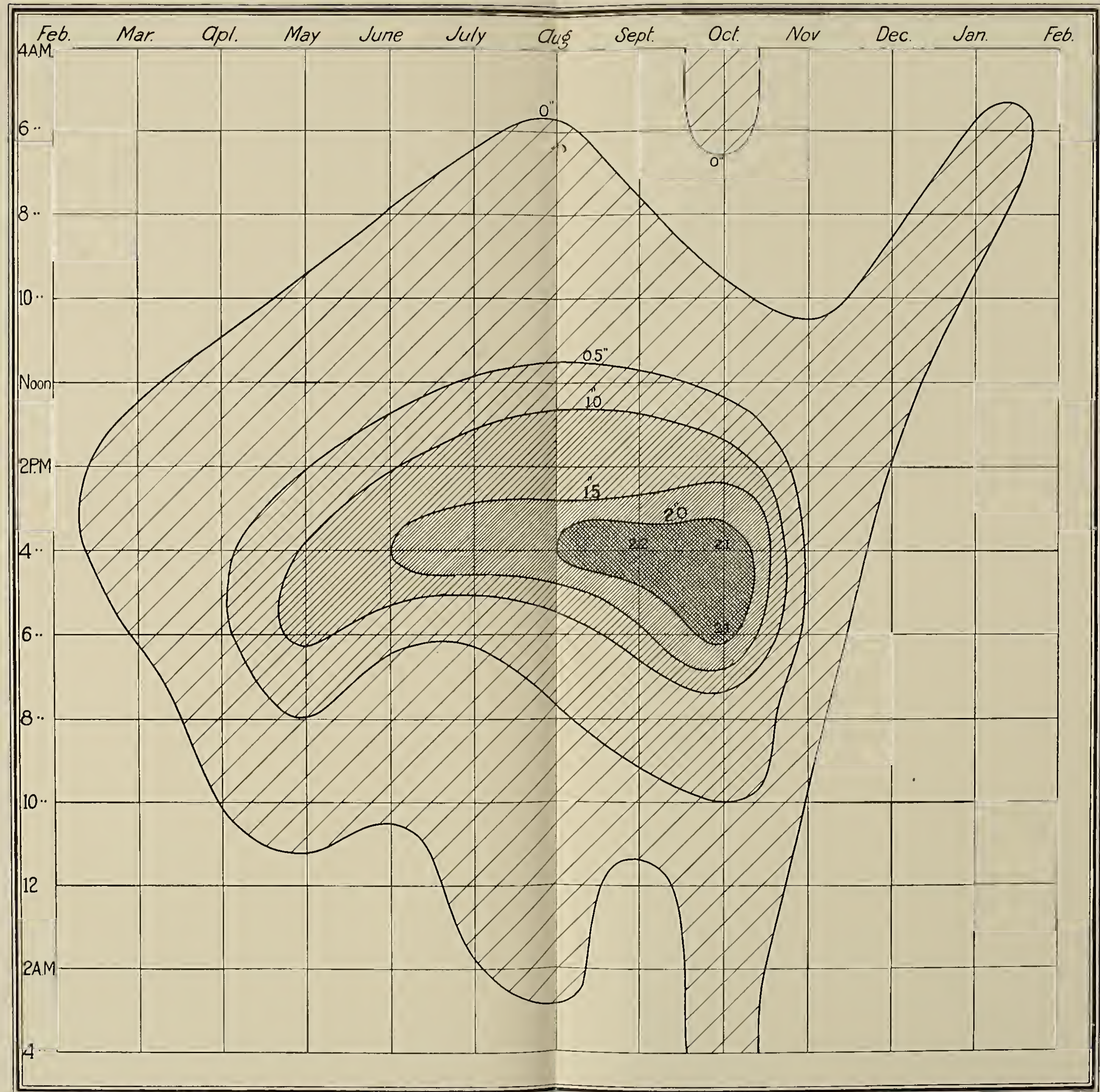
TYPES OF RAINFALL IN CENTRAL AMERICA.



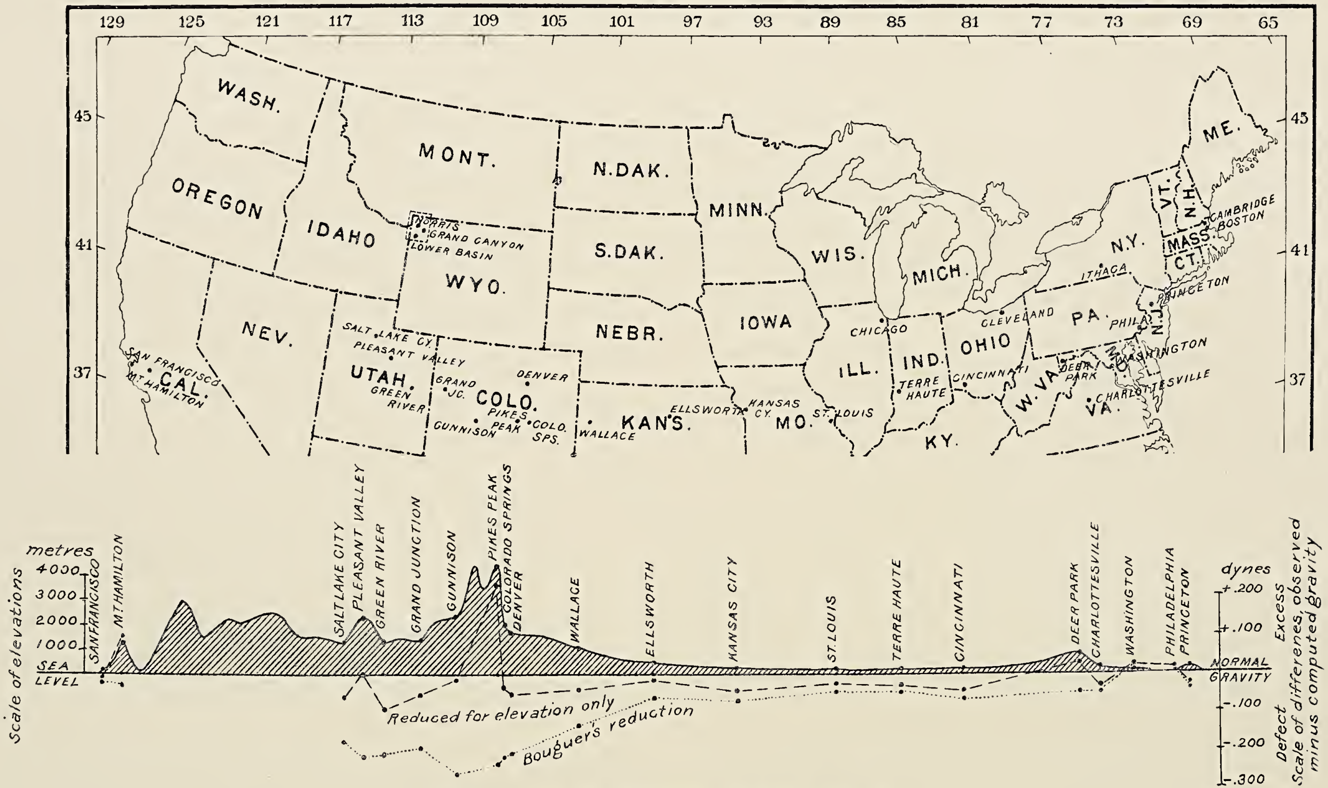
TOTAL AMOUNT OF ANNUAL RAINFALL FOR EA



UR BY MONTHS AT SAN JOSÉ, COSTA RICA.



TOTAL AMOUNT OF ANNUAL RAINFALL FOR EACH HOUR BY MONTHS AT SAN JOSÉ, COSTA RICA.



CROSS SECTION OF CONTINENT NEAR 39TH PARALLEL.

Observed minus computed gravity, with reduction to sea level made by Bouguer's formula, shown thus ....

Same, with correction for elevation only, shown thus — — — — — —

RESULTS OF A TRANSCONTINENTAL SERIES OF GRAVITY MEASUREMENTS.

BY

George Rockwell Putnam.

[Read before the Society, February 2, 1895, and published by permission of the Superintendent of the U. S. Coast and Geodetic Survey.]

The value of pendulum measurements of gravity in connection with problems important alike to geodesy and terrestrial physics can be fully developed only by their systematic distribution over the earth's surface. A prominent member of this Society wrote a few years since "pendulum observations are far too few for the wants of geographic or geologic science." The great expense and labor connected with these determinations, using the older instruments and methods, acted as such a prohibition to their extension that the entire subject was practically neglected for half a century, but within recent years interest has revived to so great a degree that the total number of stations determined is now probably five times the number available (122) when Professor Helmert, in 1880, made his elaborate discussion of pendulum observations to deduce the figure of the earth. This has been largely brought about by the introduction of more portable apparatus. A quarter meter pendulum and an elegant method of using a chronometer in observing coincidences were first employed by Lieutenant Colonel Von Sterneck, in Austria, about thirteen years ago, and the use of a half meter pendulum was developed by Commandant Def-

forges, in France, a little later. At present almost every nation carrying on geodetic surveys has taken up this subject to a greater or less extent. A few years since, Dr. T. C. Mendenhall designed for use on the Coast and Geodetic Survey a half second pendulum apparatus differing in important respects from that used in Austria, although previous to that time valuable experimental and field research had been carried on for the Survey in this line by Mr. Charles S. Peirce, Mr. E. D. Preston, and others, principally in connection with various foreign expeditions. During the past year an extensive series of gravity measurements was made in the United States with the half second pendulums, employing convenient methods not heretofore thought applicable to such small apparatus, and in addition instruments more portable than any before used, were tested. It is the purpose of the present paper to briefly describe this work and to give a summary of the results.

Measurements of the force of gravity relative to the base station, Washington, were made at twenty six stations, the fieldwork occupying 150 days. The famous series carried out in India in connection with the Great Trigonometrical Survey, comprising thirty one stations, required six years for its completion. Some allowance should, however, be made for the poor transportation facilities existing there. It is true that work more rapid than that of the past season, has been performed in Europe, but this has been done only by using approximate methods in rating chronometers and in comparing the pendulums therewith. Of the present series as planned by Dr. Mendenhall, eighteen stations follow at fairly systematic intervals the course of the transcontinental triangulation along the thirtyninth parallel as far west as Salt Lake City; the others are located further north, in the eastern and central part of the country, with three stations in the Yellowstone park. The series along the thirtyninth parallel, on account of the wide variety of orographic features traversed so nearly in the same latitude, is peculiarly well adapted to throw light on important questions, such as

the continental variation of gravity, the condition of the earth's crust, and the proper method of reduction to sea level. This line of stations, commencing at the Atlantic coast, ascends to near the crest of the Appalachians, traverses the great central plain, gradually increasing in altitude from 495 to 6,041 feet (151 to 1,841 meters); then rises to the high elevations of the main chain of the Rocky mountains, reaching an altitude of 14,085 feet (4,293 meters) at Pikes Peak; descends into the eroded valleys of the Grand and Green rivers, crosses the summit of the Wasatch ridge, and finally descends to the great western plateau of the continent.

The half second pendulum apparatus used in this work was exhibited before this Society in February, 1891, and is described in the Report of the Coast and Geodetic Survey for 1891, pages 503 to 564, so that only a brief description is needed here. The complete outfit comprised a set of three quarter meter invariable pendulums, an air tight case in which they were swung, a dummy or temperature pendulum, flash apparatus, light air pump, dry cells and various other accessories, a portable astronomical transit suitable for either time or latitude observations, a small chronograph, and an astronomical tent. Including packing cases, the whole weighed about 700 pounds (318 kilograms). The pendulums are of the new type, with agate knife-edge and plane inverted from the usual position, following the idea of Dr. Mendenhall. The case is a heavy metal one, provided with leveling screws, windows, arrangements for starting, stopping, raising, and lowering the pendulums from the outside, and is air tight when the lid is properly placed. There is a microscope for reading the arc of oscillation, and a small pendulum with level tube in its head for making the knife-edge horizontal. The temperature is obtained from a thermometer whose bulb is inserted in the stem of a dummy pendulum, which is of the same size and metal as the swinging one and is held in the case near it. The pressure is read by a small manometer hung in the case, the air being ex-

hausted to about 2.4 inches (60 millimeters) with a portable air pump. The flash apparatus is for the purpose of observing coincidences between a chronometer and a swinging pendulum. An electromagnet in circuit with a break circuit chronometer moves a shutter at the end of each second, thus throwing a flash of light through a narrow slit. The image of this slit is seen in an observing telescope as reflected from two mirrors, one moving with the pendulum and the other fixed. As the pendulum is slightly slower than the chronometer, the image reflected from its mirror will be seen in a somewhat retarded position at the end of each second, and once in five or six minutes the two images will be in the same horizontal line, which is the moment of coincidence. Between two such phenomena it is evident that the pendulum makes one less oscillation than twice the number of seconds beat by the chronometer, and hence its period is easily deduced. These pendulums are of the invariable type—the theory of their use depending on the length remaining constant except for changes due to temperature. Their periods at different stations are then inversely proportional to the square root of gravity, after allowance has been made for all variations of conditions which influence the time of oscillation. To eliminate these disturbing effects the observed periods of the pendulums require five corrections, known as the arc, temperature, pressure, rate, and flexure corrections. By applying these the periods are reduced to what they would have been under certain standard conditions, those adopted for this work being: arc, infinitely small; temperature, 15° C.; pressure, 60 millimeters at 0° C., true sidereal time and inflexible support. The arc correction is based on the usual theoretical reduction and the assumption that the arc diminishes in geometrical ratio as the time increases in arithmetical ratio. The effects of changes of temperature, pressure, and flexibility of support were investigated experimentally and coefficients deduced. An elegant comparative method, first used by Airy,* was

*Phil. Trans. of the Royal Society, 1856, p. 297.

employed for this purpose. The pendulum whose coefficients were desired was swung successively under the various conditions to be investigated, while in another room a second pendulum whose period was known was swung simultaneously under uniform conditions. By suitable electric connections the same chronometer was used in observing both pendulums and its rate deduced from the observations with the second pendulum. With this rate correction applied, the periods of the first pendulum were obtained entirely free from the irregularities of rate of chronometer. This same method, which obviates the necessity for time observations, has been applied successfully in this country and elsewhere for comparing gravity at two distant stations telegraphically connected.

The following are the corrections in seconds that were applied in reducing to standard conditions:

$$\text{Arc correction} = -\frac{PM}{32}\,\frac{\sin(\varphi+\varphi')\,\sin(\varphi-\varphi')}{\log\sin\varphi-\log\sin\varphi'},$$

where P is period in seconds, M is modulus of common logarithmic system, φ and φ' are initial and final semi-arcs.

$$\text{Temperature correction} = +0.00000419\,(15-T),$$

where T is observed temperature in degrees centigrade.

$$\text{Pressure correction} = +0.000000101\left[60-\frac{Pr}{1+.00367\,T^\circ}\right]$$

where Pr is observed pressure in millimeters, and T is temperature.

$$\text{Rate correction} = 0.00001157\,R\,P,$$

where P is period and R is daily rate on sidereal time in seconds, $+$ if losing, $-$ if gaining.

$$\text{Flexure correction} = -0.00000065\,D,$$

where D is the observed movement of the knife-edge in microns when a force of 1.5 kilograms is applied horizontally in the plane of oscillation.

The flexure coefficient used as derived from experiment differs slightly from that deduced from the theoretical for-

mula,* but the difference is unimportant in view of the small flexure actually encountered. The flexure was measured by mounting a microscope independently of the case and observing the movement of a glass scale placed above the knife-edge when a weight was applied at the end of a cord running over a pulley and attached near the edge, the force acting horizontally in the plane of oscillation. Of course, endeavor was made to have the conditions as uniform as practicable at the various stations. The arc and pressure, being controllable, were always nearly the same; favorable temperature conditions were obtained by setting up the apparatus in basement rooms wherever possible; the chronometers were well protected and not disturbed during the course of observations at a station, a hack watch taking their place in noting the instant of coincidence; and the receiver was mounted on masonry piers, stone foundations, or concrete floors, except at one station (Norris Geyser basin), where it was necessary to use wooden posts.

In this work methods not before used with short pendulums were adopted, with the result, it is believed, of saving labor and increasing accuracy. Heretofore half second pendulums have been swung either in the open air (as in Europe) or at about two thirds atmospheric pressure (as in this country). Under either of these conditions the diminution of arc is so rapid that the length of single swings has ordinarily been limited to about an hour, and this practically requires the constant attendance of the observer while the observations continue. With this method a large amount of labor (including night work) is required to make the

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*$dT = \frac{PeT}{2\lambda}\frac{h}{\lambda}$, where T is the period of the pendulum, dT is the change of period on account of flexure of the support, e is the elasticity or displacement divided by force applied, P is the weight of the pendulum, h is distance center of gravity to center of suspension, and λ is distance center of oscillation to center of suspension. See "Comptes Rendus de la Cinquième Conférence Géodesique International, 1877, Annexe I*a*, I*b*," papers by C. S. Peirce and Cellerier; also Report Coast and Geodetic Survey for 1881, Appendix 14.

swings cover the entire interval between time observations on succeeding nights; or, if this is not done, it must be assumed that the rate of the chronometer during the few hours of observation is uniform with its daily rate, an assumption which experience has shown may be considerably in error. On the construction of an improved and quite portable air pump weighing but six pounds (2.7 kilograms), designed by Mr. Fischer, chief mechanician of the Coast and Geodetic Survey, it was found possible to reduce the air pressure in the receiver to less than one tenth of an atmosphere in a few minutes, and experiment showed that at such a low pressure the length of swing could be extended to twentyfour hours if desired, though as a matter of convenience and to avoid very small arcs a length of eight hours was adopted.* An initial total arc of 55′ was used, which falls off to about 20′ in eight hours. A modification of the method of observing coincidences was also introduced. As a result of these smaller arcs the images were found to overlap for several seconds, but by taking the mean of their first and last contacts great accuracy in observation could still be obtained even when the arc became as small as 5′. Each of these pendulums was swung twice—once direct and once reversed—the observations thus extending over fortyeight hours, so as to begin and end with time observations. If these were prevented by cloudy weather the swings were continued until time was obtained, but the very favorable conditions experienced during the past season rendered this necessary in only a few cases. Usually only three coincidences were observed at the beginning and at the end of each swing, these being sufficient to give without uncertainty the total number that had occurred. Two chronometers were used in the pendulum observations, coincidences being observed alternately with each. By a suitable switch

*A plan of observation somewhat different from that here described was used on the first short trip, including the determinations at Cambridge, Boston, and Ithaca.

arrangement either could be thrown into the flash circuit or on to the chronograph. The advantage in the use of two chronometers is in the constant check that the comparison of results furnishes against errors of observation or computation, and also in the safeguard against accident to either time piece. The comparison of the average periods of the three pendulums as derived separately from the two chronometers at all the stations shows an average difference of only .0000001 second, and the maximum at any station is only .0000004 second, thus indicating practically the total elimination of errors due to diurnal irregularities of rate. By comparing the results for separate swings we have some measure of the size of these irregularities, amounting in one case to .0000027 second, which corresponds to a relative variation of daily rate of 0.5 second. The flexure of the case and support was measured at all stations and the periods corrected accordingly.

The rates were derived from observations of about eight stars made each favorable evening with a portable transit in the meridian, usually mounted on wooden posts well braced. These observations, as well as the chronometer comparisons, were recorded on a chronograph. At three stations the rates were kindly furnished by observatory authorities, and at several others fixed observatory instruments were used. The rather unusual privileges required for the suitable location of the stations in the basements of public or private buildings were always courteously granted. The astronomical tent was ordinarily set up near by. The geographical positions of the stations were obtained either by connection with known points in the vicinity or by approximate determinations, the latitude by observing a few pairs of stars by Talcott's method and the longitude by comparing the chronometer corrections at succeeding stations. The elevations adopted are mostly based on the data given in Mr. Gannett's "Dictionary of Altitudes in the United States." Approximate connection was always made between the pendulum

station and the known point by hand level. In the field-work the writer had the efficient assistance of Mr. C. E. Mendenhall at fifteen stations and of Mr. S. B. Tinsley at three stations. At eight stations the observations were conducted without aid.

To avoid objections that might be raised to swinging three pendulums upon a single knife-edge, and to guard against injury to it, an extra or standard edge was provided, upon which the pendulums were swung at Washington and at two other stations. Although the ordinary knife-edge (marked A I) had about four times as much use as the standard (marked A II), the independent determinations of the pendulum periods on the two knife-edges show a fairly constant difference, indicating no wear sufficient to materially affect the periods. Comparisons were made by a complete series of swings covering forty eight hours on each edge, and the mean periods of the three pendulums, reduced to standard conditions, are given below:

		Period on A I.	Period on A II.	Differences, A I—A II.
		s.	*s.*	*s.*
Washington, D. C..	June 23–27, 1894....	.5007124	.5007110	+.0000014
Washington, D. C..	Oct. 31–Nov. 4, 1894.	7121	7108	+ 13
Chicago, Illinois...	July 11–16, 1894....	6697	6689	+ 08
Denver, Colorado..	Sept. 5–10, 1894....	8409	8392	+ 17
		Mean...	....	+.0000013

The periods of the half second pendulums have been determined at the base station at Washington six times during the past year on knife-edge A I and using the system of eight hour swings and low pressures, with the following results: *

*The transcontinental series of observations at twenty stations was made between the fourth (June 23–27) and fifth (October 31–November 4) determinations of period at Washington given in the table.

Number.	Date.	Approximate average temperature	Corrected periods on knife-edge A I.			
			Pendulum A 4.	Pendulum A 5.	Pendulum A 6.	Mean of 3 pendulums.
			s.	*s.*	*s.*	*s.*
1	April 25–27, 1894......	16° C.	.5008406	.5006662	.5006300	.5007123
2	May 10–12, 1894.......	19	8404	6666	6304	7124
3	May 31–June 2, 1894..	17	8408	6664	6302	7124
4	June 23–25, 1894......	23	8408	6662	6302	7124
5	Oct. 31–Nov. 2, 1894...	17	8400	6656	6306	7121
6	Jan. 11–13, 1895.......	11	8404	6677	6294	7125

The agreement of the means shows a satisfactory permanency of period, and as the determinations were made at different seasons of the year and at various temperatures the results may also be taken as throwing some light on the invariability of gravity and on the reliability of the temperature coefficient, although it is possible that some of these elements compensate each other.

The value of g for each station was derived separately for each pendulum by comparing its period there with the average of its periods at Washington before and after the expedition, computing by the simple formula $g_0 = \frac{P_w^2}{P_0^2} g$. For g_w the provisional value heretofore adopted, 980.098 dynes (or centimeters in terms of acceleration), at the Coast and Geodetic Survey Office was used. This was adhered to for convenience, although an elaborate determination of the absolute force of gravity made at Washington, in October, 1893, by Commandant Defforges of the "Service Géographique" of France gave a somewhat larger value, 980.165.* Large discrepancies appear among the results of the best determinations of absolute gravity made at the base stations

* "Comptes Rendus de l'Académie des Sciences," 29 January, 1894. For description of the apparatus and elegant methods developed and used by Commandant Defforges, see "Memorial du Dépôt Général de la Guerre, tome xv, Observations du Pendule," Paris, 1894.

in Europe, as will be seen by examining the accompanying Table A of values reduced to Washington, the results ranging from 980.047 to 980.285, with a mean of 980.107 (omitting Kater's discordant result), not very different from the adopted provisional value. Of course these results involve the errors of the relative connections, which in some cases are not satisfactory, but these are thought to be small in comparison with the discrepancies in the absolute measurements themselves.

Table B gives for each station the values of g derived from each pendulum, with the mean of the three and the differences from the mean. The largest single discrepancy of any result from the mean is seen to be .006 dyne, or about its $\frac{1}{160000}$ part.

Table A.

Absolute Determinations of the Force of Gravity, with Results referred to Washington, Coast and Geodetic Survey Office (not reduced to sea level).

Number.	Observer.	Date.	Place of determination.	Apparatus.	Result reduced to Washington.	
					Length seconds pendulum.	Gravity.
					Cm.	*Dynes.*
1	Peters	1869	Berlin	Lohmeier reversible pendulum.	99.2995	980.047
2	Preston	1890	Washington	Peirce reversible pendulum.	.2998	.050
3	Sabine	1829	Greenwich	Kater convertible pendulum.	.3005	.056
4	Lorenzoni	1886	Padua	Repsold reversible pendulum.	.3007	.058
5	Anton	1878	Berlin	....	.3011	.062
6	Peters	1869	Altona	Lohmeier reversible pendulum.	.3013	.065
7	Peters	1870	Königsberg	Lohmeier reversible pendulum.	.3017	.068
8	Bessel	1826–27	Königsberg	Ball and wire, two lengths, differential.	.3021	.072
9	Peirce	1875	Geneva	Bessel reversible pendulum.	.3022	.073
10	Plantamour	1869	Berne	Bessel reversible pendulum.	.3024	.075
11	Plantamour	1865–71	Geneva	Bessel reversible pendulum.	.3028	.079
12	Mahlke	1891	Hamburg	....	.3033	.084
13	Heaviside	1874	Kew	Kater convertible pendulum.	.3036	.087
14	Peirce	1876	Berlin	Bessel reversible pendulum.	.3048	.099
15	Peirce	1876	Kew	Bessel reversible pendulum.	.3051	.102
16	Biot	1825	Padua	....	.3054	.105
17	Bessel	1835	Berlin	Ball and wire, two lengths, differential.	.3055	.105
18	Biot	1824	Milan	....	.3062	.113
19	Pucci and Pisati	1882	Rome	Bessel wire pendulum	.3065	.116
20	Oppolzer	1884	Vienna	Repsold reversible pendulum.	.3085	.135
21	Von Orff	1877	Munich	Repsold reversible pendulum.	.3088	.138
22	Messerschmitt	1889	Zürich	Repsold reversible pendulum.	.3092	.143
23	Biot	1824	Paris	....	.3098	.148
24	Borda	1792	Paris	Ball and wire	.3102	.153
25	Peirce	1876	Paris	Bessel reversible pendulum.	.3109	.159
26	Mendenhall	1880	Tokio	Ball and wire	.3114	.164
27	Defforges	1893	Washington	Two reversible pendulums, differential.	.3115	.165
28	Defforges	1888	Greenwich	Two reversible pendulums, differential.	.3134	.184
29	Defforges	1889–90	Paris	Two reversible pendulums, differential.	.3144	.194
30	Kater	1817	London	Kater convertible pendulum.	.3236	.285

TABLE B.

Values of g Computed from Each Pendulum and Knife-edge.

Number.	Station.	Knife-edge.	g (in dynes). Pendulum A 4.	Pendulum A 5.	Pendulum A 6.	Mean of three pendulums.	Differences from mean. A 4.	A 5.	A 6.
1	Boston, Mass.	I	980.381	980.381	980.384	980.382	—.001	—.001	+.002
2	Cambridge, Mass.	I	980.385	980.382	980 386	980.384	+ 1	— 2	+ 2
3	Princeton, N. J.	I	980.163	980.166	980.163	980.164	— 1	+ 2	— 1
4	Philadelphia, Penn.	1	980.183	980.182	980.182	980.182	+ 1	0	0
5	Washington (Coast and Geodetic Survey)	I, II	....	....	....	980.098			
6	Ithaca, N. Y.	I	980.284	980 288	980.285	980 286	— 2	+ 2	— 1
7	Charlottesville, Va.	I	979.922	979 925	979.926	979.924	— 2	+ 1	+ 2
8	Deer Park, Md.	I	979.920	979.923	979.920	979 921	— 1	+ 2	— 1
9	Cleveland, Ohio	I	980.225	980.225	980.230	980.227	— 2	— 2	+ 3
10	Cincinnati, Ohio	I	979.991	979.987	979.993	979.990	+ 1	— 3	+ 3
11	Terre Haute, Ind.	I	980.056	980.061	980.058	980 058	— 2	+ 3	0
12	Chicago, Ill.	I	980.267	980.262	980.264	980.264	+ 3	— 2	0
		II	980.263	980.263	980.262	980.263	0	0	— 1
13	St. Louis, Mo.	I	979.985	979.985	979 990	979.987	— 2	— 2	+ 3
14	Kansas City, Mo.	II	979.977	979.973	979.979	979.976	+ 1	— 3	+ 3
15	Ellsworth, Kan.	I	979.912	979.911	979 913	979.912	0	— 1	+ 1
16	Wallace, Kan.	I	979.743	979.735	979.744	979.741	+ 2	— 6	+ 3
17	Colorado Springs, Colo.	I	979.479	979.472	979.476	979.476	+ 3	— 4	0
18	Denver, Colo.	I	979.597	979.595	979.592	979 595	+ 2	0	— 3
		II	979 597	979 597	979.595	979.596	+ 1	+ 1	— 1
19	Pikes Peak, Colo.	I	978.940	978.939	978.941	978.940	0	— 1	+ 1
20	Gunnison, Colo.	I	979.327	979.324	979.332	979.328	— 1	— 4	+ 4
21	Grand Junction, Colo.	I	979.616	979.618	979.623	979.619	— 3	— 1	+ 4
22	Green River, Utah	I	979.626	979.619	979.620	979.622	+ 4	— 3	— 2
23	Grand Canyon, Wyo.	I	979 890	979.882	979.884	979.885	+ 5	— 3	— 1
24	Norris Basin, Wyo.	I	979.935	979 938	979.934	979.936	— 1	+ 2	— 2
25	Lower Basin, Wyo.	I	979 919	979.918	979.918	979.918	+ 1	0	0
26	Pleasant Valley, Utah	I	979 497	979.500	979.497	979.498	— 1	+ 2	— 1
27	Salt Lake City, Utah	I	979.788	979.785	979.793	979.789	— 1	— 4	+ 4

In reducing pendulum observations to the sealevel Bouguer's formula has been very generally used. This is $dg = + 2\, g \frac{H}{r} \left(1 - \frac{3}{4} \frac{\delta}{\Delta}\right)$, where dg is the correction to observed gravity, g is gravity at the sea level, H is elevation above sea level, r is radius of the earth, δ is density of matter lying above sea level, and Δ is mean density of the earth. The first term takes account of the distance from the earth's center and the second term of the vertical attraction of the matter lying between the sea level and station on the supposition that the latter is located on an indefinitely extended horizontal plain. Whenever the topography about a station departs materially from this condition a third term must be

added to the above formula, being a correction to the second term or to observed gravity on account of such irregularities.* This topographical correction will always be positive, as the effect of all deviations from the horizontal plain, whether hills or mountains rising above the station or valleys or canyons lying below it, will be to diminish the force of gravity. It is evident that an elevation of any sort exactly neutralizes the vertical attraction of a similar but inverted mass below the station level, so that the removal of both would not change the force of gravity at the station. This correction may be readily computed for any point where contour maps of the surrounding country are available by describing thereon concentric circles about the station and drawing radial lines therefrom at equal angular distances, or such a figure may be drawn on tracing paper and used on successive maps. The space included between two circles may be designated as a zone, and the part of a zone between two radii as a compartment. The vertical attraction of a cylinder of radius a, height h, and density δ on a point at one extremity of its axis will be

$$2\,\pi\delta\,(a + h - \sqrt{a^2 + h^2}).$$

As a zone is the difference between two cylinders, say of radii a and a', its vertical attraction will be

$$2\,\pi\delta\,(a - a' - \sqrt{a^2 + h^2} + \sqrt{a'^2 + h^2}).$$

The attraction at its surface, of the earth considered as a sphere is $\frac{4}{3}\,\pi\,\Delta\,r$, where Δ is the mean density and r the radius of the earth. Therefore the effect on gravity of a zone is

$$dg = \frac{3}{2}\frac{g}{r}\frac{\delta}{\Delta}\,(a - a' - \sqrt{a^2 + h^2} + \sqrt{a'^2 + h^2}),$$

which becomes with a sufficient degree of approximation when h is small compared with a

$$dg = \frac{3}{2}\frac{g}{r}\frac{\delta}{\Delta}\frac{h^2}{2}\left(\frac{1}{a'} - \frac{1}{a}\right).$$

* The method of computing this correction here described is partially similar to that given by Professor Helmert, "Geodäsie," vol. II, p. 169.

This approximate formula may be readily computed with a table of squares and reciprocals if convenient numbers are taken for a' and a, and will be sufficiently accurate except when the topography is very uneven near the station, in which case the preceding formula must be used. h is to be taken for each compartment as the difference in elevation, regardless of sign, between the station and the average surface of the compartment. As this will vary for different portions of a zone, the parts of the formula involving h must be computed separately for each compartment therein and the mean applied in the formula for the zone. When these zones have been carried to such a distance from a station that their effect becomes small, the vertical attraction for the remaining region may be computed by the formula

$$dg = \frac{3\,g\,\delta}{2\,r\,\Delta}\left(\sqrt{a^2 + h^2} - a\right),$$

where a is the outer radius of the last zone, this being the formula for the difference between an infinite plain of thickness h and a cylinder of height h and radius a. The area immediately about the station within the first circle may often be neglected as approximately level, or otherwise the effect of its irregularity may be computed by taking the difference between a cylinder and a cone, the formula becoming

$$dg = \frac{3\,g\,\delta}{2\,r\,\Delta}\left(a - \frac{a^2}{\sqrt{a^2 + h^2}}\right),$$

where a is the radius and h the difference of elevation at distance a from the station taken for each compartment separately, keeping in mind always that we are computing only the correction to the vertical attraction of an infinite horizontal plain through the station and therefore only need take account of deviations therefrom. The total correction for a station will of course be the sum of the corrections for the separate zones. Where the station is at the summit of a small hill rising out of a comparatively level country, it will generally suffice to treat the hill as a cone, without

dividing the country into compartments. The formula for this case is

$$dg = \frac{3}{2} \frac{g\ \delta}{r\ \Delta} \frac{h^2}{\sqrt{a^2 + h^2}},$$

which represents the difference between the vertical attraction of an infinite plain of thickness h and a cone of height h and radius a.

The effect of topographical irregularities has been investigated in the manner described for all the stations of the past season, using where available the contour maps of the Geological Survey. Although applied in all cases where appreciable, at only one station (Pikes Peak) was this correction found to be of real importance. This is partly due to the favorable location of the stations, but also to the fact that, except on the summit of rugged mountains or very close to their base or in deep narrow valleys, this correction must necessarily be small. The effect of placing an indefinitely extended horizontal plain 114 feet (35 meters) in thickness or a sphere 338 feet (103 meters) in diameter and of density equal to one half the mean density of the earth immediately above a station would be to diminish gravity by only .004 dyne, or about the $\frac{1}{250000}$th part, which may at present be taken as the utmost limit of probable accuracy of observation.

The question of the proper reduction of pendulum observations to the level of the sea, involving as it does the various theories of the condition of the earth's crust and affecting very materially the use of such observations in deducing the figure of the earth, is a most important one and has led to the expression of many different opinions. Bouguer's reduction, already described, has been frequently employed. Professor Helmert, in the discussion of pendulum observations in his "Höhere Geodäsie" (vol. II), develops and uses the condensation method, assuming that all the overlying material is condensed onto a surface twenty one kilometers below the sealevel. As approximately applied by him in the discussion of continental stations, this reduction amounts

to omitting the correction for attraction (second term) in Bouguer's formula, but not so in coast and oceanic island stations where the effect of the lesser density of sea water is taken into account. On the theory that the surface of the earth is in a state of hydrostatic equilibrium, M. Faye, in papers published in "Comptes Rendus," in 1880 and 1883, advocated that the continental attraction term in Bouguer's formula be omitted, but that all local deviations of the elevation of the station from the general level of the land surface or sea bottom be allowed for, as, for instance, the attraction of a mountain on a station at its summit or of an isolated island. This subject has also been discussed by Stokes, Peirce, Ferrel, and others. In the recent reports on pendulum observations in the proceedings of the International Geodetic Association, the reductions have been made by two methods—first, with Bouguer's formula, and, second, omitting the attraction term and using the reduction for elevation, and the same plan is followed in the summary of results given in Table C (see p. 48). For use in Bouguer's formula the mean density of the earth has been taken as 5.58. The surface densities used are from information kindly furnished by Mr. G. K. Gilbert, of the U. S. Geological Survey, and are based on a personal examination in many cases. These represent the estimated averages for the entire mass above sea level.

In order to be able to study the results more intelligently, the values at sea level have been compared with those computed by an assumed theoretical formula,

$$g = 978.066\,(1 + .005243\, sin^2\, \varphi),$$

which is based on Clairaut's theorem, Clarke's figure of the earth, and the assumption that gravity is normal on the eastern coast of the United States. Finally, this table gives the difference, observed minus computed gravity, for both methods of reduction to sea level. These differences are shown graphically on Plate 5 for those stations near the 39th parallel, including also two stations, San Francisco and Mount Hamilton, previously determined.

TABLE C.

Summary of Results, with Reduction to Sea Level, and Comparison with Theoretical Formula.

Number.	Station.	Latitude.	Longitude.	Elevation, H.	Surface density, δ.	g, observed.	Reductions to sea level. Elevation, $2g\frac{H}{r}$	Reductions to sea level. Attraction, $2g\frac{H}{r}\frac{3\delta}{4\Delta}$	Reductions to sea level. Topographical correction.	g reduced to sea level. Bouguer's formula, g_1.	g reduced to sea level. Corrected for elevation, g_2.	g_0, computed.	Residuals. $g_1 - g_0$.	Residuals. $g_2 - g_0$.
		° ′ ″	° ′ ″	*Meters.*		*Dynes.*	*Dynes.*	*Dynes.*	*Dynes.*	*Dynes.*	*Dynes.*	*Dynes.*	*Dynes.*	*Dynes.*
	Atlantic coast:													
1	Boston, Mass.	42 21 33	71 03 50	22	[2.5]	980.382	+ .007	—.002	.000	980.387	980.389	980.394	—.007	—.005
2	Cambridge, Mass.	42 22 48	71 07 45	14	[2.5]	980.384	+ .004	—.001	.000	980.387	980.388	980.396	—.009	—.008
3	Princeton, N. J.	40 20 57	74 39 28	64	2.44	980.164	+ .020	—.006	.000	980.178	980.184	980.216	—.038	—.032
4	Philadelphia, Penn.	39 57 06	75 11 40	16	[2.5]	980.182	+ .005	—.002	.000	980.185	980.187	980.181	+.004	+.006
5	Washington (Coast and Geodetic Survey).	38 53 13	77 00 32	14	2.3	980.098	+ .004	—.001	.000	980.101	980.102	980.087	+.014	+.015
	Washington (Smithsonian)	38 53 20	77 01 32	10	2.3	[980.100]	+ .003	—.001	.000	980.102	980.103	980.087	+.015	+.016
	Appalachian (and adjacent):													
6	Ithaca, N. Y.	42 27 04	76 29 00	247	2.4	980.286	+ .076	—.024	+.001	980.339	980.363	980.402	—.063	—.039
7	Charlottesville, Va.	38 02 01	78 30 16	166	2.65	979.924	+ .051	—.018	.000	979.957	979.975	980.013	—.056	—.038
8	Deer Park, Md.	39 25 02	79 19 50	770	2.42	979.921	+ .237	—.077	.000	980.081	980.158	980.134	—.053	+.024
	Central plains:													
9	Cleveland, Ohio	41 30 22	81 36 38	210	2.4	980.227	+ .065	—.021	.000	980.271	980.292	980.318	— 047	—.026
10	Cincinnati, Ohio	39 08 20	84 25 20	245	2.45	979.990	+ .075	—.025	+.001	980.041	980.066	980.109	—.068	—.043
11	Terre Haute, Ind.	39 28 42	87 23 49	151	2.35	980.058	+ .046	—.015	.000	980.089	980.104	980.139	—.050	—.035
12	Chicago, Ill.	41 47 25	87 36 03	182	2.63	980.264	+ .056	—.020	.000	980.300	980.320	980.343	—.043	—.023
13	St. Louis, Mo.	38 38 03	90 12 13	154	2.6	979.987	+ .047	—.017	.000	980.017	980.034	980.065	—.048	—.031
14	Kansas City, Mo.	39 05 50	94 35 21	278	2.5	979.976	+ .086	—.029	.000	980.033	980.062	980.105	—.072	—.043
15	Ellsworth, Kan.	38 43 43	98 13 32	469	2.4	979.912	+ .144	—.046	.000	980.010	980.056	980.073	—.063	—.017
16	Wallace, Kan.	38 54 44	101 35 26	1,005	2.4	979.741	+ .309	—.100	.000	979.950	980.050	980.089	—.139	—.039
17	Colorado Springs, Colo.	38 50 44	104 49 02	1,841	2.4	979.476	+ .566	—.183	+.003	979.862	980.045	980.083	—.221	—.038
18	Denver, Colo.	39 40 36	104 56 55	1,638	2.35	979.595	+ .504	—.159	+.001	979.941	980.100	980.156	—.215	—.056

	Rocky mountains:													
19	Pikes Peak, Colo	38 50 20	105 02 02	4,293	2.62	978.940	+1.321	—.465	+.048	979.844	980.309	980.083	—.239	+.226
20	Gunnison, Colo	38 32 33	106 56 02	2,340	2.65	979.328	+ .720	—.256	+.002	979.794	980.050	980.057	—.263	—.007
21	Grand Junction, Colo	39 04 09	108 33 56	1,398	2.42	979.619	+ .430	—.140	+.002	979.911	980 051	980.103	—.192	—.052
22	Green River, Utah	38 59 23	110 09 56	1,243	2.42	979.622	+ .383	—.124	+.001	979.882	980.006	980.096	—.214	—.090
23	Grand Canyon, Wyo	44 43 16	110 29 44	2,386	2.55	979.885	+ .734	—.252	+.002	980 369	980.621	980.605	—.236	+.016
24	Norris Geyser Basin, Wyo	44 44 09	110 42 02	2,276	2.5	979.936	+ .700	—.235	.000	980.401	980.636	980.606	—.205	+.030
25	Lower Geyser Basin, Wyo	44 33 21	110 48 08	2,200	2.5	979.918	+ .677	—.227	+.001	980.369	980.596	980.590	—.221	+.006
26	Pleasant Valley Junction, Utah	39 50 47	111 00 46	2,191	2.45	979.498	+ .674	—.222	+.001	979.951	980.173	980.171	—.220	+.002
27	Salt Lake City, Utah	40 46 04	111 53 46	1,322	2.3	979.789	+ .407	—.126	+.004	980.074	980.200	980.253	—.179	—.053
	Pacific coast:													
	Mt. Hamilton, Cal	37 20 ...	121 39 ...	1,282	2.4	979.646*	+ .394	—.127	[+.009]	979.922	980.049	979.952	—.030	+.097
	San Francisco, Cal	37 47 ...	122 26 ...	114	2 4	979.951*	+ .035	—.011	.000	979.975	979.986	979.991	—.016	—.005

* Determined by Dr. T. C. Mendenhall in 1891.

While it is somewhat unsafe to draw general conclusions from a single series of observations, yet the favorable and systematic situation of these stations with respect to an unusual variety of continental conditions perhaps warrants the pointing out of a few possible inferences. With Bouguer's reduction there is apparently a considerable defect of gravity on the western mountains and plateaus, increasing with the average elevation of the country. This cannot be accounted for to any great extent by a supposed abnormal condition in the mass above sea level, as it would require that that mass should have a density of zero to offset this defect. The presumption is, therefore, that there is a deficiency of density below sea level, which in general compensates the elevated masses. Contrary to a recent assertion, the residuals do not appear to have any relation to distance from the sea or to the elevation of the particular point of observation, as is shown by the fairly horizontal line under that part of the central plain (Cincinnati to Ellsworth) where the altitude is nearly the same, and the nearly equal deficiencies found at stations which, like Gunnison, Pikes Peak, Colorado Springs, and Denver, vary enormously in elevation. It is interesting to note that the defect is largest at Gunnison, which is nearest the main mass of the Rocky mountains, and not at Pikes Peak, the most elevated station. With the reduction for elevation the apparent defect of gravity largely disappears, as shown by the nearly horizontal line of residuals under the great central plains, where the altitude varies from 495 to 6,041 feet (151 to 1,841 meters), and by the average result in the mountain regions. In the latter, however, the line shows considerable departures from the normal, both positive and negative, the residuals showing a striking relation to the elevations of the stations as compared with the elevation of the surrounding country. Mount Hamilton, Pikes Peak, Pleasant Valley, and the Yellowstone Park stations are above the average level and show an excess of gravity, while the remaining Rocky Mountain stations are below the general level and all show a defect of gravity. This condition is especially marked in the case of Green River and Grand

Junction, in the bottom of great eroded valleys, and Pikes Peak station, on the summit of an isolated mountain. The residuals are not proportional to the elevation of the station itself above sea level, as is at once seen by comparing Mount Hamilton, Salt Lake, Green River, Grand Junction, and Denver, which are of nearly equal elevation. Finally, with either system of reduction the residuals point to the possibility that gravity is large on the sea coast as compared with the interior. Whether this can have any connection with the effects of erosion and deposition of continental matter is a question upon which the observations in this series are far too limited to throw any clear light, but for investigating which certain portions of the United States would furnish an excellent field.

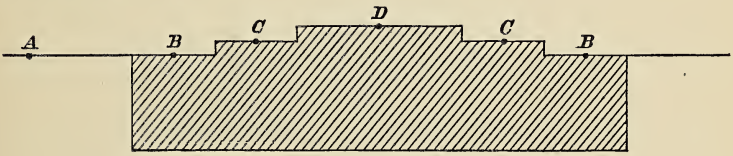

FIGURE 1.

The results of this series would therefore seem to lead to the conclusion that general continental elevations are compensated by a deficiency of density in the matter below sea-level, but that local topographical irregularities, whether elevations or depressions, are not compensated for, but are maintained by the partial rigidity of the earth's crust. The residuals with Bouguer's reduction should then be interpreted as a measure of the general deficiency of density, and, on the other hand, the residuals with the reduction for elevation only should be taken as a measure of the lack of local compensation, after allowing for uncertainties of observation and the effect of local geological conditions.

Without desiring to advocate any theory as to the conditions of the earth's crust, it is of interest to note in comparison the results for gravity that would be obtained on an iceberg floating in the ocean and having an ideal cross-section such as that shown in Fig. 1. Here the excess of matter

above the sea level is exactly compensated by the deficiency in density of the mass below as compared with sea water, but there is a lack of local compensation, and if the berg were not sufficiently rigid and strong it would bend up at the sides or split in the middle. Let gravity be measured at A on the surface of the water; at B at the same level, but over the ice; at C the average level of the surface of the ice, and at D higher than the average surface. Neglecting the fact that the different surfaces of the iceberg are not indefinitely extended, it is evident that if we reduce to sea level by allowing for the attraction of the ice lying above that level we will obtain at the three stations B, C, and D equal values for gravity, but values which are less than that at A, and that this difference will be a measure of the deficiency of density in the mass below sea level. If, on the other hand, we neglect the attraction term and reduce for elevation only, we will find as compared with A that at B gravity is in defect, at C normal, and at D in excess, and the differences at B and D will be a measure of the lack of local compensation and will be equal in amount to the attraction of a horizontal plain whose thickness is the difference in elevation between the station and the average surface. B is overcompensated and D is undercompensated—a condition maintained by the rigidity of the ice.

If we consider that these conditions apply to continental elevations, and that local irregularities in surface are not compensated by the general lack of density or other cause below sea level, we may then, following the idea of M. Faye, apply a further correction to the observed force of gravity at any point to reduce to the normal condition. This correction may be expressed $dg = 2g \frac{h}{r} \frac{3}{4} \frac{\delta}{\Delta}$, which represents the attraction of an indefinitely extended horizontal plain of thickness h and density δ, and the correction is evidently positive for stations below the average level and negative for those above. $h = H_1 - H$ where H_1 is the average elevation and H the station elevation. This method has been tested by applying it to the stations most affected in the present series,

H_1 being approximately estimated from a contour map for the country within an arbitrarily adopted radius of 100 miles of each station and the surface densities taken for δ. The resulting corrections are shown in the following Table D, together with the residuals, g observed minus g computed, under the head of Faye's reduction, when this compensation correction was applied together with the elevation and topographical corrections. For comparison the residuals are repeated from Table C for the two methods of reduction there given.

TABLE D.

Station.	Elevation.			Correction to g for lack of compensation, $\frac{h}{2g}\frac{3}{r}\frac{\delta}{4\Delta}$	Residuals, g observed — g computed.		
	Average within radius of 100 miles of station H_1.	Station H.	Difference, average minus station $h=H_1-H$.		Faye's reduction.	Reduced for elevation.	Bouguer's reduction.
Appalachian (and adjacent):	*Meters.*	*Meters*	*Meters.*	*Dynes.*	*Dynes.*	*Dynes.*	*Dynes.*
Ithaca	345	247	+ 98	+.010	—.029	—.039	—.063
Charlottesville	341	166	+ 175	+.019	—.019	—.038	—.056
Deer Park	479	770	— 291	—.029	—.005	+.024	—.053
Sums					.053	.101	.172
Central plains:							
Colorado Springs	2,258	1,841	+ 417	+.041	+.003	—.038	—.221
Denver	2,212	1,638	+ 574	+.056	+.000	—.056	—.215
Sums					.003	.094	.436
Rocky mountains:							
Pikes Peak	2,258	4,293	—2,035	—.220	+.006	+.226	—.239
Gunnison	2,724	2,340	+ 384	+.042	+.035	—.007	—.263
Grand Junction	2,251	1,398	+ 853	+.085	+.033	—.052	—.192
Green River	2,112	1,243	+ 869	+.087	—.003	—.090	—.214
Grand Canyon	2,137	2,386	— 249	—.026	—.010	+.016	—.236
Norris Geyser Basin	2,137	2,276	— 139	—.014	+.016	+.030	—.205
Lower Geyser Basin	2,137	2,200	— 63	—.007	—.001	+.006	—.221
Pleasant Valley	2,044	2,191	— 147	—.015	—.013	+.002	—.220
Salt Lake City	1,894	1,322	+ 572	+.055	+.002	—.053	—.179
Sums					.119	.482	1.969

The sums of the residuals, regardless of sign, for these fourteen stations are

With reduction by Bouguer's method........ 2.577 dynes,
" " for elevation............. ... 0.677 "
" " by Faye's method........... 0.175 "

indicating apparently a considerable advantage for the latter. It is probable that no particular significance attaches to the individual residuals remaining after this application of Faye's reduction for several reasons. Other values would certainly result if a different area were considered in estimating the average surrounding elevation or if weight were given according to proximity to the station in making this estimation or allowance made for variations in density, and further, the average elevations as given can be considered only roughly approximate, as they were calculated from a small scale map. An inspection of the table shows that the residuals with Bouguer's reduction are very nearly proportional to the average elevations surrounding each station, though bearing no relation to the actual station elevations.

As furnishing further evidence on this subject, a preliminary study has been made of several former series of gravity determinations based on Washington and carried out by Doctor Mendenhall, Mr. Preston, and Mr. Smith in various parts of the world. As these include a number of oceanic island and coast stations, it was necessary, in applying Faye's idea of reduction, to take account of the difference in density between sea water and land. This was done by assuming the water as condensed down until its density equaled that of land and using the upper surface of this condensed mass in estimating the average elevation of the surrounding region. This is equivalent to replacing the water by an equal weight of land—a proceeding which would not alter the pressure on the crust below. In application, the depth of sea water at any point multiplied by $\left(1 - \frac{\delta_1}{\delta}\right)$, where δ_1 is density of sea water and δ is density of land beneath the station, gives the depression below sea level of the condensed surface. By taking these depressions as negative altitudes the average elevation may be conveniently estimated for all stations surrounded either wholly or in part by water, the principal difficulty being the lack of sufficient data as to ocean depths and land elevations and the uncertainty in regard to the area to be considered. A similar treatment could be applied

to continental stations where the adjacent regions varied considerably in density. The approximate average elevations within a radius of 100 miles were estimated in this manner for the stations in these series, taking mean values for the density of land (2.56) and of sea water (1.03). The observed values of gravity were then reduced to sea level by both Bouguer's and Faye's methods,* and the results compared with those computed with the same theoretical formula as before. The residuals were averaged for each geographical group of stations, including those of the past season, and they are given for each method of reduction plotted to scale in Fig. 2. This diagram shows graphically the excess of gravity on islands and the defect on continents when the sealevel reduction is

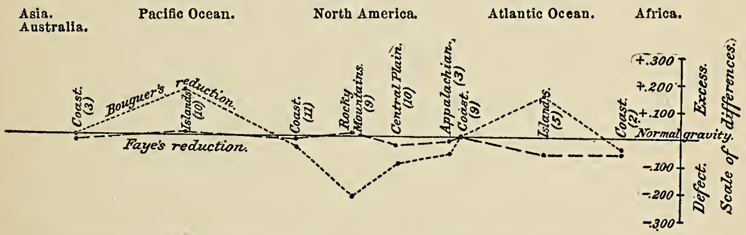

FIG. 2.—Differences observed minus computed gravity (in dynes) from C. and G. S. observations. The figures in parenthesis show the number of stations included.

made by Bouguer's formula, as has been pointed out from other series of observations. These apparent anomalies very largely disappear, however, on applying the theory of Faye. Important light would be thrown on this subject by the measurement of gravity on the open sea, which may some day be accomplished by working on large fields of ice.

The true reduction of gravity observations to sea level would therefore appear to be one that would take account

* In both of these methods as here used corrections are applied for elevation, topography, and surface attraction, and they differ only in the last. In Bouguer's formula the vertical attraction of the mass above sea level is subtracted, while in the method here called Faye's reduction allowance is made for the attraction of a plain whose thickness represents the lack of local compensation, as already explained. This latter reduction has not heretofore been developed in any definite mathematical form.

not only of the attraction of the matter above the sea level, but also of the general differences of density below, as well as of the local lack of compensation, if the latter can be proved to have a systematic relation to the topographical situation of the point of observation, as is strongly indicated by the results of the past season. With such a reduction it is quite possible that the so-called anomalies of gravity will largely disappear, and that the distribution of gravity on the earth's surface will be found to follow Clairaut's law sufficiently closely to greatly enhance the value of pendulum observations in relation to the problem of the earth's figure. The most distinguished of living geodesists recently wrote: " Pendulum measurements will become a most important means of help, not only to geodesy, but also to geology. The widest possible extension of pendulum observations is in the highest measure to be desired for both sciences."*

Mean Density of the Earth from Pikes Peak Pendulum Observations.—A value for the mean density of the earth has been deduced from the gravity measurements made on the summit of the peak and at Colorado Springs, near the base. This method of comparing the mass of a mountain which may be estimated with the unknown mass of the earth has been used on several previous occasions, but not, it is believed, under as favorable conditions as the present, for in this case contour maps of the peak and surrounding country were available, and the mountain itself was found to be composed of rock of an unusually uniform density. Mr. Whitman Cross, of the U. S. Geological Survey, who has studied the geology of the vicinity, furnished data in regard to the specific gravity of the rock of which the peak is composed. Twelve specimens determined under the direction of Mr. Gilbert gave results as follows: 2.57, 2.60, 2.61, 2.61, 2.62,

* " Nach dem Vorstehenden wird die Pendelmessung nicht nur für die Geodäsie, sondern auch für die Geologie als ein äusserst wichtiges Hülfsmittel auzusehen sein. Möglichste Ausbreitung der Pendelmessungen ist für beide Wissenschaften in hohem Maasse erwünscht." "Die Schwerkraft im Hochgebirge." Prof. F. R. Helmert, Berlin, 1890.

2.67, 2.57, 2.58, 2.61, 2.61, 2.63, 2.71. The mean value, 2.615, has been adopted.

The difference in gravity at the base and summit of a mountain is, by Bouguer's formula,

$$dg = 2g\frac{H}{r}\left(1 - \frac{3\,\delta}{4\,\Delta}\right) = 2g\,\frac{H}{r} - \frac{3\,g\,\delta}{2\,r\,\Delta}H,$$

considering the upper station as on an infinite horizontal plain, the lower station as unaffected by the attraction of the mountain, and neglecting the insignificant effect of change in centrifugal force. Here H is the difference in elevation of the two stations (2,452 meters), r the radius of the earth, δ the density of the mountain (2.615), and Δ the mean density of the earth. The correction to observed gravity for local topographical irregularities (or departure from the condition of a horizontal plain) was computed for these two stations as described in discussing the reduction to the sea level and found to be for Pikes Peak $+\frac{3\,g\,\delta}{2\,r\,\Delta}\,439$, and for Colorado Springs $+\frac{3\,g\,\delta}{2\,r\,\Delta}\,27$ (using the meter as unit of length). The observed values of gravity were for Pikes Peak 978.940, and for Colorado Springs 979.476, to which must be applied the above corrections for topographical irregularities to obtain dg for the above formula, which then becomes:

$$dg = \left(979.476 + \frac{3\,g\,\delta}{2\,r\,\Delta}\,27\right) - \left(978.940 + \frac{3\,g\,\delta}{2\,r\,\Delta}\,439\right) =$$

$$\frac{2\,g}{r}\,2452 - \frac{3\,g\,\delta}{2\,r\,\Delta}\,2452;\ \text{or}\ \Delta = 2.153\,\delta = 5.63.$$

The value for the mean density of the earth derived from the Pikes Peak observations is therefore 5.63. In this computation no account has been taken of the estimated difference in density below the level of Colorado Springs.

Quarter second Pendulum Apparatus.—With the idea of obtaining instruments still more portable than those heretofore used for measuring relative gravity, there was constructed about a year ago, as planned by Doctor Mendenhall,

a set of quarter second pendulums, with receiver and flash apparatus correspondingly reduced in size. In general principles these are similar to the half second apparatus, although there was added an ingenious device, designed by Mr. Fischer, for starting and stopping the pendulum, and the flash apparatus is somewhat different. The pendulum receiver is about 5 inches by 6 inches (13 centimeters by 15 centimeters) and 7 inches (17 centimeters) high, and may be exhausted with the portable air pump to 1.5 inches (40 millimeters) in half a minute. The pendulums weigh about 0.7 pound (300 grammes) each. The entire apparatus, with its packing cases, weighs about 106 pounds (48 kilograms), and is undoubtedly the smallest and most compact ever used for the purpose. The relative sizes of three types of pendulums are shown on Fig. 3, *P* being the Peirce reversible meter pendulum, *A* the half second, and *C* the quarter second, all drawn to the same scale.

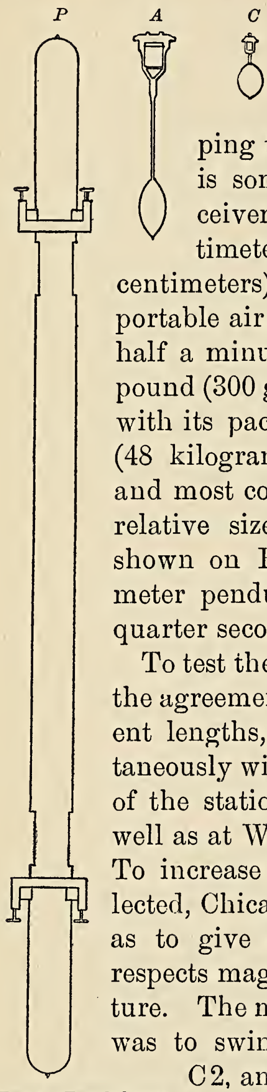

Fig. 3.—Pendulums. $\frac{1}{12}$ natural scale.

To test the efficiency of this apparatus, as well as the agreement of results with pendulums of different lengths, these pendulums were swung simultaneously with the half second pendulums at three of the stations of the transcontinental series, as well as at Washington, before and after this work. To increase the value of the test, the stations selected, Chicago, Denver, and Pikes Peak, were such as to give a maximum range of conditions as respects magnitude of g and difference of temperature. The method adopted in using the apparatus was to swing each of the three pendulums, C1, C2, and C3, once in each position, with an air pressure of 40 millimeters, initial total arc about 1° 20′, and length of swing 4 hours. Both sets of apparatus were always set up in the

same room, but sufficiently distant to not affect each other. The temperature and pressure coefficients were determined at Washington by swinging under different conditions in the manner before described, and the flexure coefficient was computed from the theoretical formula. The flexure was always measured, using the same appliances as with the *A* apparatus and a weight of 1.5 kilograms. The corrections to the observed periods were applied in the same manner as with the half second pendulums, substituting the following coefficients: Temperature, 0.00000235; pressure, 0.000000066; flexure, 0.00000037. The periods were reduced to the standard conditions—arc infinitely small; temperature, 15° C.; pressure, 40 millimeters at 0° C., sidereal time, and inflexible support. The mean period of the three pendulums at Washington in June, 1894, was *s*.2502400 and in November *s*.2502392. This change may be due in part to the fact that the knife-edge was nearly new when used in June. The following are the results for gravity as given by each pendulum, with the mean for the three and the differences from the mean of each:

Station.	*g* (in dynes).				Differences from mean.		
	Pendulum C 1.	Pendulum C 2.	Pendulum C 3.	Mean of three pendulums.	C 1.	C 2.	C 3.
Washington	....	....	....	980.098			
Chicago	980.246	980.254	980.247	980.249	—.003	+.005	—.002
Pikes Peak	978.940	978.941	978.955	978.945	— 5	— 4	+ 10
Denver	979.595	979.591	979.592	979.593	+ 2	— 2	— 1

From the agreement of the pendulums and the accord of the results with those obtained with the more elaborate observations with the half second apparatus, it is indicated that quarter second pendulums may give results of nearly the same order of precision as larger instruments. Their smallness, however, renders their use inconvenient in some respects, and the increased labor of observing resulting from the necessarily shorter swings tends to offset the gain in

portability. As the weight of the pendulum apparatus itself is not more than half that of the entire outfit necessary for accurate gravity measurements, a reduction in it alone is not a very important gain in ordinary work. Undoubtedly there will be special cases, however, where this saving of weight will be an important consideration, and for such this apparatus will be most valuable.

Comparisons of Results with Different Pendulums.—A good opportunity to compare relative gravity results as obtained with pendulums of different length and principle is afforded by the past season's work from the fact that the half and quarter second pendulums were swung at four stations in common, and also because four of the stations had been occupied in 1893 by Commandant Defforges, who used his three-quarter second (one-half meter) reversible pendulum. Below are given the comparative results, all based on the same value at Washington, the stations being arranged in the order of magnitude of g. The results with the half second pendulums on both knife-edges are included, and also two stations of Defforges on the Pacific coast, where comparison is made with results obtained in 1891 with a different set of half second pendulums. In all cases the places of observation were practically identical.

Station.	Elevation.	Results for gravity (not reduced to sea level).				Differences.	
		A. ½ second pendulums on knife A I.	B. ¼ second pendulums on knife A II.	C. ¼ second pendulums.	D. Defforges.	A — C.	A — D.
	Meters.	*Dynes.*	*Dynes.*	*Dynes.*	*Dynes.*	*Dynes.*	*Dynes.*
Chicago	182	980.264	980.263	980.249	980.276	+.015	—.012
Washington	14	.098	.098	.098	.098	.000	.000
San Francisco	114	979.951	....	....	979 947	....	+.004
Salt Lake City	1,322	.789	....	....	.747	....	+.042
Mt. Hamilton	1,282	.646	....	....	.614	....	+.032
Denver	1,638	.595	979.596	979.593	.615	+.002	—.020
Pikes Peak	4,293	978.940	....	978.945	....	—.005	

NOTES ON THE GRAVITY DETERMINATIONS REPORTED BY MR. G. R. PUTNAM

BY

GROVE KARL GILBERT

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1. *Corrections based on the Local Geology.*

By some physicists it is thought probable that the material of the earth's crust is highly rigid, and that by this rigidity the continents are upheld. By others it is thought more probable that the earth's crust is somewhat plastic, and that the continents stand high because their material is light. The question of high rigidity *versus* isostasy affects the theories of geologists, and hence they are interested in the diagnosis of the crust by means of the pendulum. American geologists have reason to be specially interested in the recent pendulum work of the Coast Survey, not only because the efficiency of the new apparatus enables it to multiply accurate measurements with unprecedented rapidity, but because the results are related to geologic provinces with whose structure we are acquainted. Already much light has been thrown on the problem of crustal rigidity, and it is hardly rash to look forward to a satisfactory solution if the work is continued for a few years with equal energy and skill.

Last autumn I followed in Mr. Putnam's tracks so far as to visit ten of his stations, namely, Colorado Springs, Denver, Wallace, Ellsworth, Kansas City, St. Louis, Terre Haute, Chicago, Cincinnati, and Cleveland. At each station I examined the local geology with reference to the density of

the formations and the influence of their peculiarities of density on the local attraction. Special attention was given also to the records of deep borings, and beyond the depths penetrated by borings the characters of the sedimentary rocks were afterwards inferred from a variety of geologic data, gathered, chiefly by others, in localities more or less remote. The results may in each case be regarded as rough approximations, but they serve fairly well the purpose of this inquiry, which was to determine whether a correction to the observed gravity may advantageously be based on such information as the geologist can adduce as to the density of the subjacent rocks.

In Table I column 2 gives the observed value of gravity, in dynes, after correction for latitude, altitude, topography, and the attraction of matter between the surface at the station and sealevel beneath it. The latitude correction was a reduction to 40°; the altitude correction, a reduction to sealevel. The topographic correction, in effect, substitutes a level plain for the diversified topography about the station.* The correction for the attraction of matter above sealevel recognizes the theory of high rigidity, and in the treatment of observations distinguishes that theory from the theory of isostasy. It gives, indeed, an imperfect recognition, because under that theory the sealevel, or geoid of reference, rises in continental regions above the spheroid of reference, thus making the apparent altitude too small, but it is probable that this imperfection does not affect the qualitative results of the present inquiry.

Column 3 gives the same values as column 2, except that the correction for the attraction of matter above sealevel was omitted. As compared with column 2, it represents the theory of isostasy.

Column 4 gives the geologic correction. At each station the surface rocks are sedimentary and have small dip. The sedimentaries vary in thickness from one-half mile to three

* The nature of the topographic correction is described by Mr. Putnam on pages 43–46. I employed the values computed by him.

TABLE I.

The Application to Gravity Determinations of a Correction for the Density of the Local Rocks.

1. Station.	2. Gravity corrected for latitude, altitude, topography, and attraction of matter above sealevel.	3. Gravity corrected for latitude, altitude, and topography.	4. Correction for density of sedimentary rocks.	5. Gravity as per column 2, corrected for sedimentary rocks. (Column 4.)	6. Gravity as per column 3, corrected for sedimentary rocks. (Column 4.)	Departures from mean of quantities in columns 2, 3, 4, 5, and 6. 2a.	3a.	4a.	5a.	6a.
	Dynes.	*Dynes.*	*Dynes.*	*Dynes.*	*Dynes.*	*Dynes.*	*Dynes.*	*Dynes.*	*Dynes.*	*Dynes.*
Cleveland	980.135	980.158	+.008	980.143	980.166	+.055	+.009	—.008	+.047	+.001
Cincinnati	980.114	.141	+.005	980.119	.146	+.034	—.008	—.011	+.023	—.019
Terre Haute	980.132	.149	+.015	980.147	.164	+.052	.000	—.001	+.051	—.001
Chicago	980.141	.161	+.006	980.147	.167	+.061	+.012	—.010	+.051	+.002
St. Louis	980.136	.153	+.006	980.142	.159	+.056	+.004	—.010	+.046	+.006
Kansas City	980.110	.141	+.007	980.117	.148	+.030	—.008	—.009	+.021	—.017
Ellsworth	980.115	.167	+.015	980.130	.182	+.035	+.018	—.001	+.034	+.017
Wallace	980.033	.145	+.019	980.052	.164	—.047	—.004	+.003	—.044	—.001
Colorado Springs	979.940	.146	+.026	979.966	.172	—.140	—.003	+.010	—.130	+.007
Denver	979.945	.128	+.056	980.001	.184	—.135	—.021	+.040	—.095	+.019
Mean	980.080	980.149	.016	980.096	980.165	.064	.009	.010	.054	.009

miles, and the nature of the crystallines beneath them is not known. The crystallines were assumed to have an average density of 2.70. The mean density of the sedimentary column at each station was subtracted from 2.70 and the remainder multiplied by the thickness of the sedimentaries. The products were used in the subsequent computations, yielding the quantities of the column.

Column 5 shows values under the theory of high rigidity (column 2) as modified by the geologic correction (column 4). Column 6 shows values under the theory of isostasy (column 3) as modified by the geologic correction.

The formation of the remaining columns depends for its justification on the postulate that the ideal result of the correction of pendulum observations is uniformity. If all local conditions were duly accounted for, the resulting values would be identical for all stations. Therefore, in seeking to ascertain whether the use of a doubtful correction is advisable, it is proper to ask whether its application tends towards uniformity of result. To that end I have brought out the comparative discordance of the various sets of values by subtracting the mean of each set from the several values of the set and tabulating the remainders.

These appear (for columns 2, 3, 5, and 6) in columns 2*a*, 3*a*, 5*a*, and 6*a*. At the foot of each of these columns is given the mean of its numbers, regardless of sign, and these means are considered to be indices of the discordance of the sets. The mean of numbers in column 4*a*, derived from the geologic corrections, may be regarded as an expression of the average quantitative effect of the geologic corrections in modifying the inequalities of the gravity determinations.

Putting the results of the comparison into words:

(1.) The discordance, .064 dyne (column 2*a*), of values derived from the theory of high rigidity is reduced to .054 dyne (column 5*a*) by the application of the geologic correction. It is reduced by the entire quantitative effect of that correction, .010 dyne (column 4*a*).

(2.) The values derived under the theory of isostasy have

a discordance of .009 dyne (column $3a$), and this is not reduced by the geologic correction, but remains .009 dyne (column $6a$).

So far as the discussion of ten stations may warrant a general conclusion, that conclusion would appear to be that corrections based upon the densities of the accessible rocks may be applied with advantage to observations discussed under the theory of high rigidity, but not to observations discussed under the theory of isostasy. It is well to hold lightly a generalization from so small a number of particulars, but this one is strengthened by certain theoretic considerations. Under the isostatic theory the mass of each unit column of earth matter is approximately the same, differences of mean density being compensated by differences of altitude, and variations from the mean in one part of the column being compensated by opposite variations in other parts. Allowance for the density peculiarities of a part should not therefore be made. Under the theory of high rigidity there is no compensatory adjustment, and correction may properly be made for any local peculiarity which is discovered.

2. *Bearing of the Observations on the Theory of Isostasy.*

In view of the prospect that the present chain of stations will soon be expanded into a system, a comprehensive discussion of the results would be premature, but there may be advantage in considering their general bearing. Preliminary discussion is an important part of the interaction of theory and observation, and if the general tendency of present results can be discovered, the selection of future stations may be more effective.

Let us postulate that the greatest features of the earth's relief, such as continents and great plateaus, are sustained isostatically, and that the small features, such as hills and small mountains, are within the competence of terrestrial rigidity, and then let us inquire what the pendulum work of the Coast Survey has to tell of the status of features of

intermediate size, namely, the greater mountains and smaller plateaus.

Between the Rocky and Appalachian mountains stretches a vast plain, 1,200 miles in its smallest dimension. For at least five of the great periods of geologic chronology it has been exempt from orogenic corrugation, and the topographic evidences of earlier corrugation have been practically obliterated. Here, if anywhere on the continent, isostatic equilibrium should be established. For this reason I have taken the average gravity of this region as normal and used it as a standard of comparison. Eleven stations fall within the district—the ten enumerated above and Ithaca, New York.

Before taking the mean of the values at these stations, one more adjustment was made—the adjustment to the mean plain. The topographic correction adjusts the value for gravity to the hypothetic condition of the surface which would result if the neighboring hills and mountains were removed down to the level of the station and the neighboring valleys were filled up to the same level. Ordinarily this implies a change in the quantity of matter and a consequent disturbance of isostatic equilibrium. If instead of this we conceive the mountains to be graded down to such a level that the removed material exactly fills the valleys, we hypothetically leave the isostatic relations undisturbed. It is manifest that in a discussion like the present, which postulates general isostasy and seeks to learn the limitations of isostasy, assumptions falsifying the regional load should be avoided if possible. To adjust the values from the hypothetic plain at the level of the station to the hypothetic mean plain it is necessary to add or subtract the attraction of a plate of rock as thick as the space between the two plains. When the station is below the mean plain the correction is additive; when above, subtractive.

The amount of the correction and sometimes its sign depend on the extent of the district averaged to determine the height of the mean plain. The diameter of the proper district is a function of the rigidity of the crust and requires

for its determination the discussion of an elaborate system of stations. Probably an inner circle should be given greater weight than outer rings, and some attention should be paid to geologic provinces. The corrections here used were determined from circular districts having a radius of thirty miles and without the use of weights.* Of the circles about Denver and Colorado Springs only those parts belonging to the Great plains were used. It was assumed that the very different history of the mountain region at the west barred it from use in the determination of the standard value of gravity. The corrections obtained were: Ithaca +.006; Ellsworth, +.002; Colorado Springs, +.009; Denver, +.008.

In the second column of Table II are the altitudes of the stations. The third column contains the correction in dynes for reduction to mean plain. In the fourth column are the values of gravity at the stations after correction for latitude, altitude, local topography, and height of mean plain. The fifth column gives the residuals after subtracting the mean of the eleven from the individual values. The average residual, .008 dyne, is a measure of the discordance of the results for the several stations. The residuals may also be used to determine the probable error, .002 dyne, of the mean gravity, 980.151 dynes, regarded as a standard, under the isostatic hypothesis, for the discussion of the remaining stations of the chain; and they can be used to determine the probable error, ±.007 dyne, of the value derived from a single station of the interior plain. It is to be noted that the probable error for the single station includes not only errors arising from the evaluation of the various corrections and errors of observation, but all local departures of the plain

* When these paragraphs were written I had not seen Mr. Putnam's manuscript. My "reduction to mean plain" is his "Faye's reduction" (pp. 47, 52–55). His term is preferable, but I let my lines stand unchanged, because there is some interest in the fact that we independently selected the same method of discussion. Our numerical results differ chiefly because he used a radius of 100 miles and I a radius of 30 miles in computing the correction.

from isostatic adjustment. Its small amount gives confidence not only in the high precision of the observations, but in the postulate that the interior plain is approximately in isostatic equilibrium.

TABLE II.

Gravity at Eleven Stations of the Interior Plain.

1. Station.	2. Altitude above tide.	3. Reduction to mean plain.	4. Gravity after reduction to mean plain.	4a. Departure from mean of quantities in column 4.
	Feet.	*Dynes.*	*Dynes.*	*Dynes.*
Ithaca	810	+.006	980.151	.000
Cleveland	689	.000	.158	+.007
Cincinnati	804	.000	.141	—.010
Terre Haute	495	.000	.149	—.002
Chicago	597	.000	.161	+.010
St. Louis	505	.000	.153	+.002
Kansas City	912	.000	.141	—.010
Ellsworth	1,538	+.002	.169	+.018
Wallace	3,296	.000	.145	—.006
Colorado Springs	6,038	+.009	.155	+.004
Denver	5,373	+.008	.136	—.015
Mean	....	....	980.151	.008

The mean value of gravity for the interior plain, 980.151 dynes, having been thus assumed as a standard for the discussion of the results at the stations of the chain, it was subtracted from the values obtained at the several stations, after they had been corrected for latitude, altitude, and local topography. The residuals appear in column 4 of Table III. A correction for mean plain (column 5) was then applied, giving a new set of residuals (column 6). In the computation of this correction a circular district with 30 miles radius was used, as before, except at Pikes Peak, where the part falling within the interior plain was neglected, and

in the Yellowstone park, where topographic data were not adequate, and a rectangular district was substituted. In tabulating the results a column has been added to aid in the appreciation of their quantitative value. It shows in feet the thickness of sheets of rock (indefinitely broad) competent to produce the local deviations from normal gravity, or, coining a convenient term, it expresses the excess or defect of gravity in *rock-feet.*

The local measurements will be discussed with reference to the geologic provinces in which the several stations fall. West of the interior plain are the Rocky mountains of Colorado and Montana, the Colorado plateau province, the Wasatch plateau, and the Desert ranges. East of it are the Appalachian mountains, the Piedmont plain, and the Atlantic coastal plain.

TABLE III.

Gravity at Stations West and East of the Interior Plain.

1. Station.	2. Altitude of station.	3. Altitude of mean plain.	4. Excess of gravity over 980.151 dynes.	5. Correction to reduce to mean plain.	6. Excess of gravity after reduction to mean plain.	7. Excess of gravity (column 6) expressed in rock-feet.
	Feet.	*Feet.*	*Dynes.*	*Dynes.*	*Dynes.*	*Rock-feet.*
Pikes Peak	14,084	8,640	+.259	—.181	+.078	+ 2,300
Gunnison	7,677	9,050	+.026	+.046	+.072	+ 2,200
Grand Canyon	7,830	7,850	+.049	+.001	+.050	+ 1,500
Lower Geyser Basin	7,218	7,850	+.039	+.021	+.060	+ 1,800
Norris Basin	7,465	7,850	+.063	+.013	+.076	+ 2,300
Grand Junction	4,586	6,560	—.019	+.066	+.047	+ 1,400
Green River	4,078	5,340	—.057	+.042	—.015	— 400
Pleasant Valley Junction	7,189	7,500	+.035	+.010	+.045	+ 1,300
Salt Lake City (*a*)	4,336	4,340	—.020	.000	—.020	— 600
Salt Lake City (*b*)	4,336	5,840	—.020	+.050	+.030	+ 900
Deer Park	2,525	2,080	+.057	—.015	+.042	+ 1,300
Charlottesville	544	830	—.001	+.009	+.008	+ 200
Princeton	210	200	+.005	.000	+.005	+ 100
Boston	72	117	+.028	+.001	+.029	+ 900
Washington	46	220	+.048	+.006	+.054	+ 1,600
Philadelphia	52	(?)	+.039	[+.006]	+.045	+ 1,300

Pikes Peak and Gunnison stations are within the Rocky mountains of Colorado, the first being on a high summit, the second in a deep valley. The district may be described as a plateau 150 miles broad from east to west, consisting of several structural ridges or crustal corrugations, each of which is divided into minor ridges by deep valleys of erosion. Though many of its peaks stand 8,000 feet above the adjacent parts of the interior plain, its average height above that datum is only 2,000 to 3,000 feet. Gravity at the two stations exceeds the isostatic requirement by 2,300 and 2,200 rock-feet. The evident suggestion is that the whole Rocky Mountain plateau, regarded as a prominence on a broader plateau, is sustained by the rigidity of the lithosphere. The group of stations in Yellowstone park repeats the suggestion for the Rocky mountains of Montana. That upland is about 80 miles broad, and its average height above Big Horn valley, at the east, and Snake valley, at the west, is between 2,000 and 3,000 feet. It consists in part of mountain corrugations and in part of volcanic accumulations. The three stations indicate gravitational excesses of 1,500, 1,800, and 2,300 rock-feet. In each case the upland may be conceived to have originated from the horizontal compression of some crustal tract and the consequent upthrust of superficial portions—a process which would result in local excess of matter approximately to the full extent of the uplift. Excess would continue until the protuberance was removed by erosion.

The Colorado plateau province has a width, between the Rocky mountains of Colorado and the Wasatch plateau, of 175 miles. Its characteristic is bodily uplift (at various dates since Cretaceous time), with subsidiary corrugation. Historically and structurally it is intermediate between the Rocky mountains and the Great plains, but more nearly related to the plains. It is drained by the main branches of the Colorado river and is undergoing rapid degradation. The two gravity stations within it give widely divergent indications. At Grand Junction the apparent excess is 1,400 rock-feet; at Green River there is an apparent defect

of 400 rock-feet. This discrepancy of 1,800 rock-feet is not accounted for by any known facts of local structure. The stations rest on the same geological formation and are similarly related to broad arches of strata. If we assume that the area of the mean plain of reference is much too small, and that the broad district behaves as a unit, the difference in the general degradation about the two stations accounts for two-thirds of the discrepancy. The mean plain of a circular tract with 100 miles radius and including both stations has an estimated altitude of 6,000 feet, and reference to this gives the Grand Junction station an excess of 800 rock-feet and the Green River station an excess of 200 rock-feet. These are not more discordant than some of the stations of the interior plain.

The Wasatch plateau in the vicinity of the Pleasant Valley gravity station is 50 miles wide and may be called a single, broad, low corrugation. Its average height above adjacent lowlands is 1,500 to 2,000 feet. The gravity station is in an eroded valley near its eastern edge, and the measurement indicates an excess of 1,300 rock-feet.

From the Wasatch plateau and its northward continuation, the Wasatch range, westward to the Sierra Nevada stretches the province of the Desert ranges, 450 miles broad. It is a corrugated plateau, and differs from the other provinces in that it loses no material by degradation. The waste from its ridges is stored in its valley troughs. If the ridges rise because light and the troughs sink because heavy, then, as degradation unloads the ridges and loads the troughs, whatever lag there may be between cause and effect should find expression in a defect of gravity on the ridges and an excess of gravity in the troughs. The Salt Lake City station stands on the alluvial load of a trough near the base of the Wasatch range. Assuming trough and ridge to have the isostatic relation outlined, the proper plain of reference is the mean plain of the trough, and that has about the same altitude as the station. This assumption (*a*, Table III) yields a small defect of gravity instead of the excess theoretically anticipated.

If, on the other hand, there was no initial contrast in density between range and trough and their relation is sustained by rigidity, there should be an excess of matter under the ridges and a defect, either relative or absolute, under the troughs. The looser aggregation of the detrital material in the troughs should make the actual contrast of attraction somewhat greater than would be estimated from the configuration alone. Under this assumption the mean plain of reference for any station should include ridge and valley alike, and high stations should in general show, after reduction to mean plain, a stronger attraction than low stations. Including in the reduction so much of the Wasatch and Oquirrh ranges as lie within 30 miles of Salt Lake City, we obtain an excess of 900 rock-feet (*b*, Table III). This points toward a general excess of gravity for the province, but little reliance can be placed on the indication of a single station.

One station only, Deer Park, belongs to the Appalachian mountains. Once the scene of pronounced corrugation, the Appalachian belt has been base-leveled, then raised in broad, flat arches, and finally dissected by streams. In the latitude of Deer Park its average altitude above neighboring plains is between 1,000 and 1,500 feet, a difference accordant with its excess of attraction, 1,300 rock-feet.

The Piedmont plain has been long exempt from corrugation, was gently lifted in connection with the arching of the Appalachian belt, and has been degraded almost to the same extent. Theoretically, an indication of equilibrium should be anticipated. Charlottesville and Princeton give nominal excesses, 200 and 100 rock-feet. Boston, which is doubtfully assigned to this province, gives an excess of 900 rock-feet, an anomaly for which no adequate explanation has been suggested.

Washington, with an excess of 1,600 rock-feet, and Philadelphia, with an excess of 1,300, stand at the "fall-line" which divides the Piedmont and coastal plains. West of this line there has been much degradation in Cenozoic and

later Mesozoic time; east of it there has been much sedimentation. The stations stand in a transition zone where degradation has been followed by moderate sedimentation. Here again the excess of matter is not explained.

In view of the magnitude of the deviations from isostasy thus developed, the question may pertinently be raised whether the isostatic theory is more advantageous than the theory of high rigidity as a basis for the discussion of the observations. Though this question is practically answered by a comparison of the reduced values Mr. Putnam has tabulated and illustrated, there is some reason for adding in this connection the result of a partially independent computation. As already stated in discussing the geologic correction, the theory of high rigidity is represented in the reduction by the correction for the attraction of material above sealevel. The isostatic theory is represented by the omission of that correction and the addition of the correction for reduction to mean plain. Taking the 26 stations for which the mean plain correction has been computed and completing the reduction under the isostatic theory, I then subtracted the mean of the measurements from the individual measurements and found an average residual of .026 dyne. Treating the same measurements according to the theory of high rigidity and employing the same procedure in other respects, I obtained an average residual of .156 dyne. The extreme range in the first case is .093 dyne; in the second, .591 dyne. The measurements are thus seen to be six times as discordant from the point of view of rigidity as they are from the point of view of isostasy.

Summary.—The measurements of gravity appear far more harmonious when the method of reduction postulates isostacy than when it postulates high rigidity. Nearly all the local peculiarities of gravity admit of simple and rational explanation on the theory that the continent as a whole is approximately isostatic, and that the interior plain is almost perfectly isostatic. Most of the deviations from the normal arise from excess of matter and are associated with uplift.

The Appalachian and Rocky mountains and the Wasatch plateau all appear to be of the nature of added loads, the whole mass above the neighboring plains being rigidly upheld. The Colorado Plateau province seems to have an excess of matter, and the Desert Range province may also be overloaded. The fact that the six stations from Pike's Peak to Salt Lake City, covering a distance of 375 miles, show an average excess of 1,345 rock-feet indicates greater sustaining power than is ordinarily ascribed to the lithosphere by the advocates of isostasy.

It indicates also that the district used in this discussion for estimating the height of the mean plain, is far too small; even the radius of 100 miles selected by Mr. Putnam may not be large enough.

Future Work.—In my judgment it will be advantageous to give early place in future work to a group of stations so arranged as to yield data for the discussion of the proper method of computing the mean-plain or Faye correction. For this purpose a district of bold relief is preferable and a contour map is essential. The requirements are probably best met in the Rocky mountains of Colorado.

It is a question of great interest whether the central part of the Great Basin, a broad district of ancient and modern corrugation, but without net gain or loss from surface action, is in equilibrium. Its discussion requires a chain of stations from Promontory, Utah, to Wadsworth, Nevada.

The postulated isostasy of the interior plain is of such importance as to deserve further test. If really in equilibrium the plain not only gives a standard of reference for other districts, but affords a valuable field for the redetermination of the latitude constant of the formula for local gravity. I suggest a set of stations in North Dakota and Montana and another set in Texas. The Texas set might also be compared with a set in Louisiana for the purpose of contrasting gravity in regions of rapid degradation and rapid deposition.

The single Appalachian measurement suggests a question as to the hypogene changes connected with gentle arching of the surface, the question whether there is horizontal transfer of matter or only expansion. There would be much interest in the results of other measurements in the same region.

A study of the anomaly at the fall-line promises to throw light on the general question of isostatic adjustment between regions of progressive degradation and deposition. For its prosecution there should be several stations on each side of the fall-line.

NEW CLOUD CLASSIFICATIONS.

BY

ALEXANDER McADIE.

[Read before the Society, March 2, 1895.]

Our cloud names date from the beginning of the century. At a meeting of the Askesian Society, session of 1802–'3, a young chemist of Tottenham read an essay in which he proposed the terms stratus, or sheet, cumulus, or heap, and cirrus, or feather, for cloud names. These terms combined with one another and with nimbus, or rain, were sufficient to designate all ordinary types of cloud. One other attempt at cloud classification had been made; but Howard's classification was so superior and the scheme so flexible and easy of comprehension that the Howardian system at once received recognition. The essay itself was reprinted, translated into various languages, and in later years has been adopted almost without change by the different meteorological services. The classification is one based entirely upon cloud appearance. Beginning with the lowest, the seven types are—

Nimbus, or rain.
Stratus, or layer.
Cumulo-stratus, or combination of layer and heap.
Cumulus, or mass.
Cirro-cumulus, or feather and heap.
Cirro-stratus, or feather and sheet.
Cirrus, or feather.

Convenient symbols for representing these were also devised by Howard. The system is unsatisfactory, however, in this: that, being based purely upon appearance, no account is taken of the origin and manner of formation of the cloud. Clouds of very dissimilar origin may have a similar appearance. Modern meteorology demands more than a record of the appearance of the cloud. It seeks the meaning of each formation and regards the cloud as an exponent of the physical processes operating in the air and resulting in cloudy condensation. The cloud is primarily valuable not on account of its beauty, but because it makes manifest motion in the atmosphere, which is not otherwise discernible. It outlines to some degree the storm mechanism at different levels in the atmosphere. Making due allowance for the fact that the cloud does not always give the true motion of the current in which it moves, as witness the Table cloud at Table mountain, it is still, when rightly interpreted, a most significant index of air motion. There is no sound reason why the forecaster should not derive as much information concerning the movements of the air from a cloud map as from a pressure or temperature map. A happy illustration of the practical use to which a cloud map can be put may be found in the storm of August 26–'7–'8–'9, 1893, more familiarly known as the Sea Islands storm, in which 1,100 lives were lost. (Wall map shown illustrating cloud movement over the southeastern section of the country.) South of Savannah, the telegraph lines being down, reports were missing. It was of the utmost importance at a time like this to locate the storm center as accurately as possible in order to determine its future probable course. No pressure readings in southern Florida or Georgia were available; yet, even with this rough system of cloud observation and report, it is obvious that the upper clouds at Lynchburg, Knoxville, Chattanooga, and Norfolk locate the "low" on the Georgia coast, and the chart makes plain that the upper clouds at Knoxville were probably moving from the

southeast instead of from the south, as reported, and the upper clouds at Knoxville given as calm were probably moving from the east. A stratus cloud at Cincinnati has been mistaken for a cirro-stratus. If this much can be done without a close and sharp cloud definition, how much could have been obtained from cloud observations taken in accordance with the system to be mentioned below!

At the International Meteorological Conference held in Munich in 1891 the question of improving our cloud nomenclature was discussed, and a committee, consisting of Professor Hann, Professor Hildebrandsson, Professor Mohn, and Messrs. Riggenbach, Rotch, and Tiesserence de Bort, was appointed to prepare a cloud atlas. At the International Conference at Upsala, in 1894, this committee recommended the cloud classification of Hildebrandsson, Abercromby, and Köppen, adding the word "diurnal" to one of the cumulus groups. The new international classification thus recognizes ten principal forms:

a. Detached or rounded forms (most frequent in dry weather).

b. Widespread or veil-like forms (wet weather).

A. Highest clouds; mean height, 9,000 meters:
- *a* 1, cirrus.
- *b* 2, cirro-stratus.

B. Clouds of mean altitude, 3,000 to 7,000 meters:
- *a* 3, cirro-cumulus.
- 4, alto-cumulus.
- *b* 5, alto-stratus.

C. Low clouds, 2,000 meters:
- *a* 6, strato-cumulus.
- *b* 7, nimbus.

D. Clouds formed by diurnal ascending currents:
- 8, cumulus; top, 1,800 meters; base, 1,400 meters.
- 9, cumulo-nimbus; top, 3,000 to 8,000 meters; base, 1,400 meters.

E. Elevated fog below 1,000 meters.
- 10, stratus.

The International Nomenclature.

Descriptions of the Clouds (modified from those in the Hildebrandsson-Köppen-Neumayer Atlas).

1. Cirrus (Ci.). *Isolated feathery clouds of fine fibrous texture, generally of a white color;* frequently arranged in bands which spread like the meridians on a celestial globe over a part of the sky and converge in perspective towards one or two opposite points of the horizon. (In the formation of such bands Ci. S. and Ci. Cu. often take part.)

2. Cirro-Stratus (Ci. S.). *Fine whitish veil,* sometimes quite diffuse, giving a whitish appearance to the sky, and called by many cirrus haze, and sometimes of more or less distinct structure, exhibiting tangled fibers. The veil often produces halos around the sun and moon.

3. Cirro-Cumulus (Ci. Cu.). Fleecy cloud. *Small white balls and wisps without shadows, or with very faint shadows, which are arranged in groups and often in rows.*

4. Alto-Cumulus (A. Cu.). Dense fleecy cloud. *Larger whitish or grayish balls with shaded portions, grouped in flocks or rows, frequently so close together that their edges meet.* The different balls are generally larger and more compact (passing into S. Cu.) towards the center of the group and more delicate and wispy (passing into Ci. Cu.) on its edges. They are very frequently arranged in lines in one or two directions.

(The term cumulo-cirrus is given up as causing confusion.)

5. Alto-Stratus (A. S.). *Thick veil of a gray or bluish color,* exhibiting in the vicinity of the sun and moon a brighter portion, and which, without causing halos, may produce coronæ. This form shows gradual transitions to cirro-stratus, but, according to the measurements made at Upsala, has only half the altitude.

(The term strato-cirrus is abandoned as giving rise to confusion.)

6. STRATO-CUMULUS (S. Cu.). *Large balls or rolls of dark cloud which frequently cover the whole sky, especially in winter,* and give it at times a wave-like appearance. The stratum of strato-cumulus is usually not very thick, and blue sky often appears in the breaks through it. Between this form and the alto-cumulus all possible gradations are found. It is distinguished from nimbus by the ball-like or rolled form and because it does not tend to bring rain.

7. NIMBUS (N.). Rain clouds. *Dense masses of dark, formless clouds with ragged edges,* from which generally continuous rain or snow is falling. Through the breaks in these clouds there is almost always seen a high sheet of cirro-stratus or alto-stratus. If the mass of nimbus is torn up into small patches, or if low fragments of clouds are floating under a great nimbus, they may be called fracto-nimbus ("scud" of the sailors).

8. CUMULUS (Cu.). Piled clouds. *Thick clouds whose summits are domes with protuberances, but whose bases are flat.* These clouds appear to form in a diurnal ascensional movement which is almost always apparent. When the cloud is opposite the sun the surfaces which are usually seen by the observer are more brilliant than the edges of the protuberances. When the illumination comes from the side this cloud shows a strong actual shadow. On the sunny side of the sky, however, it appears dark with bright edges. The true cumulus shows a sharp border above and below. It is often torn by strong winds, and the detached parts (fracto-cumulus) present continual changes.

9. CUMULO-NIMBUS (Cu. N.). Thunder cloud; shower cloud. *Heavy masses of clouds rising like mountains, towers, or anvils, generally surrounded at the top by a veil or screen of fibrous texture* ("false cirrus") *and below by nimbus-like masses of cloud.* From their base generally fall local showers of rain or snow and sometimes hail or sleet. The upper edges are either of compact cumulus-like outline and form massive summits surrounded by delicate false cirrus, or the edges themselves are drawn out into cirrus-like filaments.

This last form is most common in "spring showers." The front of storm clouds of wide extent sometimes shows a great arch stretching across a portion of the sky which is uniformly lighter in color.

10. STRATUS (S.). Lifted fog in a horizontal stratum. When this stratum is torn by the wind or by mountain summits into irregular fragments they may be called fracto-stratus.

The above description is from Mr. A. Lawrence Rotch's translation of the minutes of the Conference, in the "American Meteorological Journal," December, 1894, the Conference having requested that all translations should be made under official supervision.

It will be seen that this classification takes some account of the cloud's altitude; and in differentiating clouds formed by diurnal ascending currents in calm air, generally of the summer cumulus type, from the clouds formed by widespread general uplifting of the vapor, some of the nimbus formations, this classification takes some account of cloud origin. In both of these directions the new system is preferable to the old; but the criticism can be fairly made that in the matter of cloud origin the new classification does not go far enough.

There are many different ways in which a cloud can be formed. The ordinary summer cumulus cloud is formed by a slow and somewhat limited ascensional movement. Nothing like this, however, takes place in the formation of the familiar billow clouds. Here one layer of air glides over another of different density, and waves result, the condensation marking very prettily the wave action. Again, many of the lowermost clouds are formed by contact cooling. The so-called ground fog occurs when the ground has been cooled by radiation, and you notice that the cloud grows from the ground upward. Finally, in some of the cumulo-nimbus or thunder clouds there can be little doubt that electricity plays some part in the formation and rapid enlargement of the cloud. This monarch of clouds is noteworthy in several

ways. Its monstrous size indicates a formation out of the common. Imagine Mont Blanc (14,134 feet high) lifted into the air and set down upon Mount Washington (6,279 feet), and you have a fair idea of the dimensions of a medium-sized cumulo-nimbus cloud. The water in this cloud may be cooled below the freezing point and yet not frozen. A snowflake or ice crystal falling into it may start sudden congelation, and this, in connection with the electrical conditions, to be alluded to later, may explain the sudden and puff-like elongations so characteristic of this cloud.

In addition to the direction and relative velocity of the cloud (the only conditions which have been thus far recognized or utilized in forecasting), it is demanded of the future cloud classification that it take into account the level in which the cloud is formed and the manner of formation. Some such scheme as the following might be profitably used:

Altitude.	Formation.			
	Cooling by contact.	Mixture.	Ascension.	Electrical and critical.
Up to 250 meters	Fogs—haze, dust, and ground fogs.		Nimbus	
500		Scud		
750	Nocturnal radiation.	Stratus	Summer cumuli	Hail clouds.
1,000		Cu-stratus	Cumulo-nimbus	Cumulo-nimbus.
1,500		Billows		
2,000				
3,000			Cumulus	
4,000		Ci-cumulus	Alto-cumulus	
5,000		Cirro-stratus		
Above		Cirrus		

The altitudes have been kept down purposely, because half of the whole amount of vapor in the air is below us at a height of 1,800 meters (less than 6,000 feet), and it is but fair to assume that the clouds of most importance to us in forecasting are those formed below 2,000 meters. Above 8,000 meters there is practically no water vapor. Most of our clouds are formed under the second heading (mixture), where condensation results from the mixing of two imperfectly saturated currents. Where the mixing is not thorough,

but confined to the edges, we have billow clouds; but while mixture is the most common cause of cloud formation, the cloud thus formed is not apt to give heavy rain. Clouds formed under the third heading (ascension), on the contrary, do give heavy rains. Here the cooling is by adiabatic expansion, and the ideal type of this formation is the cloud of the early afternoon in the tropics, with its torrential rain. Under the fourth heading (electrical) the cloud may keep adding to itself because of a very high surface electrification, or a cloud may be in such a critical condition that, as said above, the slightest jar suffices to produce great change. It is conceivable that a cloud burst may be a sudden change of condition.

A classification by origin and level gets rid of the confusing "alto," or lower, which is still retained—unfortunately, we think—in the international classification. This is such a handy word that it is liable to be overworked. Thus in the first of the following classifications we have "high alto-cumulus" and "low alto-cumulus."

Classification of Clouds according to Prof. W. M. Davis; Elementary Meteorology, p. 179 (*Blue Hill, Mass. values*).

12 Types.

Kind of cloud.	Summer height.	Winter height.
	m.	*m.*
Cirrus	9,923	8,051
High cirro-stratus	8,754	7,846
Low cirro-stratus	6,481	2,930
Cirro-cumulus	7,606	6,992
High alto-cumulus	6,406	....
Low alto-cumulus	3,168	2,884
Strato-cumulus	2,003	....
"False cirrus"	8,242	....
Cumulo-nimbus	....	....
Cumulo-nimbus (base)	1,202	1,552
Cumulus (top)	2,181	....
Cumulus (base)	1,473	1,381
Nimbus	712	....
Stratus	583	503

Classification of Clouds according to Rev. Clement Ley, "Cloudland," pp. 26, 27.

26 Types.

Clouds of radiation:

Nebula, fog.
Nebula pulverea, dust fog.
Nebula stillans, wet fog.

Clouds of interfret:

Nubes informis, scud.
Stratus quietus, quiet cloud.
Stratus lenticularis, lenticular cloud.
Stratus maculosus, mackerel cloud.
Stratus castellatus, turret cloud.
Stratus præcipitans, plane shower.

Clouds of inversion:

Cumulo-rudimentum, rudiment cloud.
Cumulus, heap cloud.
Cumulo-stratus, anvil cloud.
Cumulo-nimbus, shower cloud.
Nimbus, rainfall cloud.
Cumulo-stratus-mammatus, tuberculed anvil cloud.
Cumulo-nimbus grandineus, hail shower.
Cumulo-nimbus nivosus, snow shower.
Cumulo-nimbus mammatus, festooned shower cloud.
Nimbus grandineus, hail-fall.
Nimbus nivosus, snow-fall.

Clouds of inclination:

Nubes fulgens, luminous cloud.
Cirrus, curl cloud.
Cirro-filum, gossamer cloud.
Cirro-velum, veil cloud.
Cirro-macula, speckle cloud.
Cirro-velum mammatum, draped veil cloud.

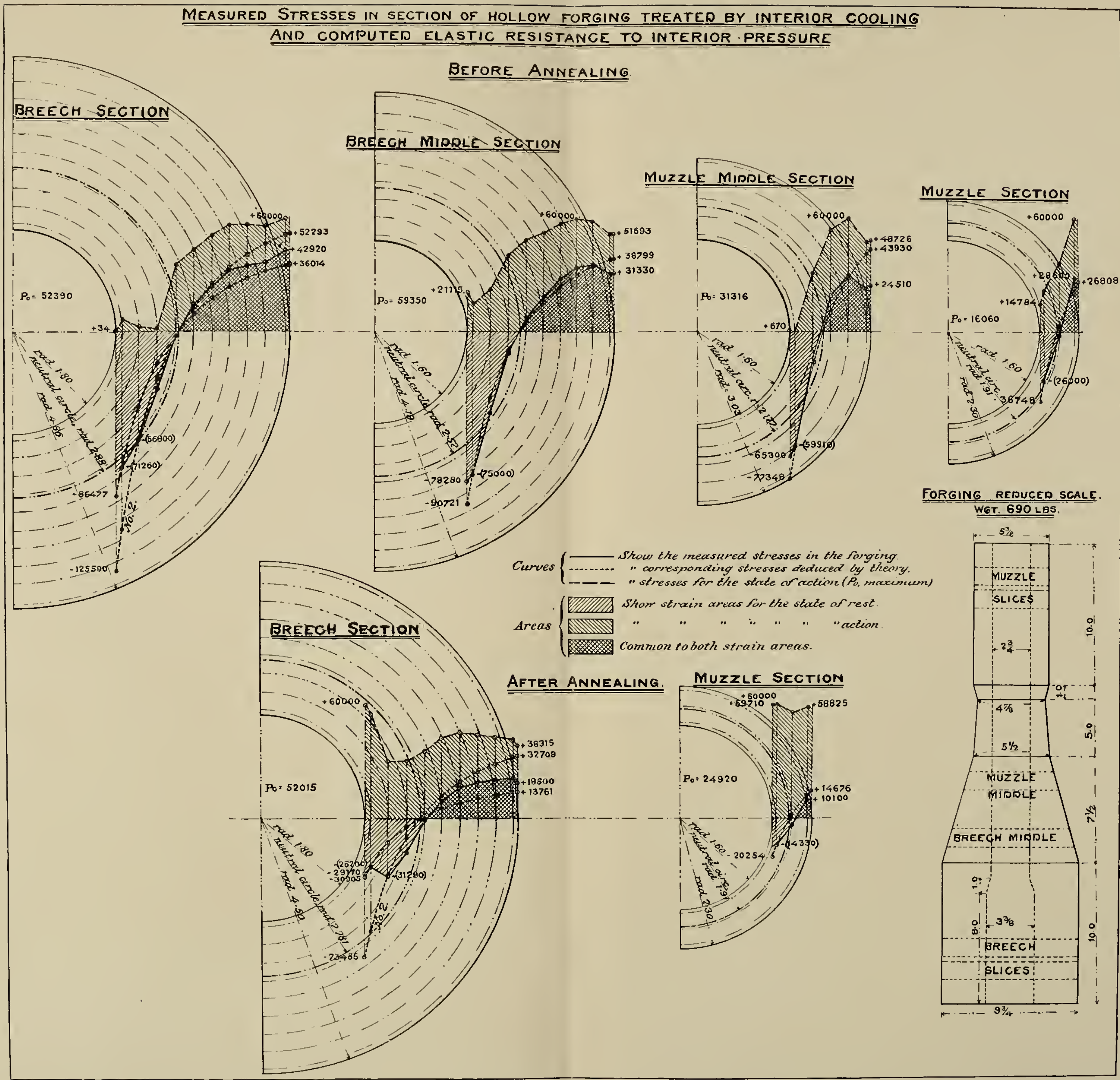
Ley's classification recognizes the principle of origin. The first cause of formation, called radiation, corresponds to the division in our scheme called cooling by contact. Perhaps the right term to employ would be "contact and radiation," and what we have called mixture, Ley calls "interfret," and our "ascension" is called "inversion." A fourth cause, which is called inclination, we find it hard to place. It concerns the highest clouds of all, such as the cirro-filum and the luminous clouds. Finally, in order to get at the cloud's true meaning we must, in addition to equipping our observers with nephoscope and cloud atlas,

have systematic measurements of the cloud height. This is now done at Blue Hill, Upsala, Storlein, and Berlin by means of theodolites and double observing stations. A more direct way and one which we think is entirely practicable is to send apparatus up into cloudland by means of kites. This would give us the conditions prevailing at different cloud levels, and the records would not be momentary.

Two other ways of investigating water vapor conditions at some distance above the ground may be alluded to: First, by means of the spectroscope. No less than 928 absorption lines due to aqueous vapor have been mapped. Dr. L. Becker has given three groups; one of 678 lines, with wave-lengths 6020–5666 ten-millionths of a millimeter; the second containing 106 lines of wave-lengths, 5530 to 5386, and the third having 116 lines, with wave-lengths 5111 to 4981.

The infra-red portion of the spectrum is probably particularly rich in water vapor lines, and with the determination of an intensity scale for these terrestrial lines, the distribution of vapor in the air may become known.

Second, by means of the electrometer. In noticing the formation of cumulo-nimbus clouds we alluded to the part played by electricity. We have measured with a sensitive quadrant electrometer the pull in volts experienced by the air between one of these clouds and the earth. We could tell of the approach of the cloud while yet far off, and by the changes in the potential could roughly map out the sky. This may therefore be a second way in which to determine the water vapor at a distance. The electrometer has the advantage of the spectroscope as a cloud detector in two ways: it can be used at night, and whereas the spectroscope ceases to be available when the cloud is at all dense, the electrometer does not.



STRESSES IN GUN FORGINGS.

STEEL CYLINDERS FOR GUN CONSTRUCTION—STRESSES DUE TO INTERIOR COOLING.

BY

ROGERS BIRNIE.

[Read before the Society May 11, 1895.]

This experiment is the first important step taken by the Ordnance Department of the United States Army to investigate the merits of making cannon from a single steel forging with initial tension produced by interior cooling. The experiments of similar import with reference to built-up or hooped steel guns which were made by this department in 1884–'6 established on a very firm basis the manufacture in this country of that description of gun, and it is not improbable that the present investigation may lead to equally important results for the single forging construction.

The inception of this work is due to Captain Frank Hobbs, of the Ordnance Department, and the experimental forging was furnished, through his instrumentality, by the Bethlehem Iron Co. The subject has received attention in other places, particularly in the interesting work of General Nicholas Kalakoutsky,* of the Russian artillery, but up to this time guns have not been made upon the plan proposed. At Le Creusot, France, interior cooling has, however, been used to improve the condition of cylinders used in built-up guns. As to the treatment of the forging, it may suffice to say that its preparation was similar to that of a forging intended for a hooped gun, by the usual methods of casting,

*Kalakoutsky (General Nicholas). Investigations into the internal stresses of cast iron and steel. London, George Reveirs, 1888.

forging, annealing, oil-tempering and annealing. In the final annealing, while still in the annealing furnace and uniformly heated to redness, water was passed into and through the bore of the forging until it was cool enough to handle.

The several circular sections shown in the drawings, each about 0.5 of an inch thick, were then cut from different parts of the forging to ascertain the strains in concentric elementary cylinders of which the section may be conceived to be composed. Each section was marked to be divided into a number of circular rings about 0.15 of an inch in radial thickness. Before cutting out these rings datum points were marked on the face of each to measure two diameters at right angles. The rings were removed consecutively and measurements of the diameters made at each stage of the operation. The change in diameter of a ring on being released from the section is taken as a measure of the circumferential strain or stress to which it was subjected in the forging. A ring which expands on being released was evidently under circumferential compression in the forging, and one which contracts was under tension. The datum points for the curves of initial tension shown in the figures are derived from the difference in the original diameters of the rings and their diameters after release. As seen in these curves, the compression is greatest at or near the surface of the bore, whence it gradually decreases to zero at the neutral point. At this point the strains of tension begin and increase gradually toward the exterior of the cylinder. The strains of compression and extension are in equilibrium.

Duplicate sections from the breech and muzzle ends of the forging are illustrated, the originals being taken directly after the treatment by interior cooling and the duplicates when the parts of the forging to which they belonged had been subjected to partial annealing. The object of this treatment was to show how the strains originally produced could be controlled and ameliorated, if necessary, by annealing a forging after interior cooling.

The accuracy of the results is of course dependent upon the measurements of diameters. Of this, however, there is every indication that proper care and skill were exercised. The measurements were made with a micrometer scale and read to the fractional part of $\frac{1}{10000}$ of an inch. The sensitiveness of the results is such that an error of $\frac{1}{10000}$ of an inch in the reading of an average diameter (five inches) corresponds to 600 pounds per square inch in the expressed stress of tension or compression.

Deductions from the Application of the Formulas for Gun Construction.—These and other similar experiments show the favorable condition of strains produced in a hollow forging by interior cooling. The strains are analogous to those produced by shrinkage in the built-up construction and serve the same purpose. The present experiments are particularly instructive in that they deal with a hollow forging of varying thickness of wall, with sectional dimensions corresponding to the service field gun.

The strains directly produced by the treatment are found to be more intense than is necessary and show the desirability of an amelioration of that treatment in future operations; but the strains left after annealing the treated forging are moderate and satisfactory. The elastic resistance of the sections, both before and after annealing, is shown to be superior to that of corresponding sections of the built-up field gun. This, however, is in part attributable to higher qualities of metal.

The physical qualities of the forging, determined from tensile-test specimens taken from it after treatment, are as follows:

	Breech end.	*Muzzle end.*
Elastic limit, pounds per square inch..........	68,000	75,500
Tensile strength, " " " "	126,500	128,400
Ultimate extension, per cent..................	9.50	11.625
Reduction of area, " "	12.14	16.35

For present purposes the elastic limit for extension will be taken at a reduced value, $\theta = 60{,}000$, and the elastic limit for compression will be defined in each section by the actual

measurements made, the highest being $\rho = 78{,}280$ at the bore of the breech middle section. It will be understood that the stated measured stresses correspond to the measured strains per inch for a modulus of elasticity, $E = 30{,}000{,}000$ pounds. For example, the value of ρ just stated is derived as follows:

$$\rho = \frac{0.00835 \text{ (strain)}}{3.2 \quad \text{(diameter)}} \, 30{,}000{,}000 = 78{,}280 \text{ (stress)}. \qquad (1)$$

The sections taken for examination are the breech, breech middle, muzzle middle, and muzzle before annealing, and the breech and muzzle after annealing. In the dimensions of these sections we have nearly the counterpart of four principal cross sections of the 3.2-inch field gun.

The principal objects of discussion will be—

1. To compare the measured stresses in the forging after treatment with those anticipated by theory and required to make the resistance to interior pressure a maximum. This will show the degree of uniformity in the actual stresses and how nearly they conform to the requirements of the law for maximum resistance.

2. Taking the actual stresses as measured in each section, to determine the elastic resistance of the section to interior pressure. This, while admitting every irregularity of the stresses or strains induced by the treatment, will give a final measure of its efficacy.

The formulas* to be applied, which are fundamentally the same as those for the built-up construction, relate to a gun or cylinder made of a single piece, with initial tension produced by interior cooling.

$$\theta_u = \tfrac{2}{3} \, \frac{P}{\left(\frac{R_1}{R_0}\right)^{\frac{2}{3}} - 1} = a\,P \qquad (2)$$

$$P_u = \frac{3\,(R_1^2 - R_0^2)\,\rho}{(4\,R_1^2 + 2\,R_0^2) - 3\,(R_1^2 - R_0^2)\,a} \qquad (3)$$

---

*For these formulas *see* Gun Making, Appendix B, Military Service Institution Monograph, 1888.

In these equations P_u is the interior pressure per square inch which, if applied, would produce an uniform stress, θ_u, in the whole thickness of the wall of the cylinder, depending only upon the dimensions of the cylinder and the initial compression ρ.

$$\theta = \left[\frac{2\,R_0^2}{3\,(R_1^2 - R_0^2)} + \frac{4\,R_1^2\,R_0^2}{3r^2\,(R_1^2 - R_0^2)}\right] P \qquad (4)$$

In this θ is the *increase* of stress caused at radius r by the application of any interior pressure, P, within the limit of elasticity of the cylinder.

$$\rho = -\left[\frac{2\,R_0^2}{3\,(R_1^2 - R_0^2)} + \frac{4\,R_1^2\,R_0^2}{3r^2\,(R_1^2 - R_0^2)}\right] P_u + \theta_u \qquad (5)$$

In this ρ is the *relief* of stress at radius r, with given values of P_u and θ_u, under the assumption that the pressure P_u has been applied and is withdrawn.

Replacing θ_u in (5) by its value as expressed in (2) and designating by ρ_1 a stress at radius r_1, the ratio of the stresses at two different points in the wall may be expressed by

$$\rho = \left[\frac{\dfrac{1}{\left(\dfrac{R_1}{R_0}\right)^{\frac{2}{3}} - 1} - \dfrac{R_0^2}{R_1^2 - R_0^2} - \dfrac{2\,R_1^2\,R_0^2}{(R_1^2 - R_0^2)\,r^2}}{\dfrac{1}{\left(\dfrac{R_1}{R_0}\right)^{\frac{2}{3}} - 1} - \dfrac{R_0^2}{R_1^2 - R_0^2} - \dfrac{2\,R_1^2\,R_0^2}{(R_1^2 - R_0^2)\,r_1^2}}\right] \rho_1 \qquad (6)$$

From this the stress ρ at a given radius, r, may be determined when ρ_1 for the radius r_1 is given. The symbols ρ and ρ_1 in this equation may express either compression or tension.

The radius of the circle on which should be found the neutral point of every curve of stress incident to the system at rest is found from the equation

$$r = R_1 \sqrt{\frac{2\left(\dfrac{R_0}{R_1}\right)^{\frac{2}{3}} - 2}{\left(\dfrac{R_1}{R_0}\right)^2 - \left(\dfrac{R_1}{R_0}\right)^{\frac{2}{3}}}} \qquad (7)$$

Additional formulas deduced from those given in Appendix B, "Gun Making," can be given to determine, first, the changes in the stresses at given radii due to reaming out or enlarging the bore of a cylinder under initial tension; second, the changes due to turning off or reducing the exterior of the cylinder. Such formulas would be useful in the practical working of this method, but it will be sufficient to state here that any reduction of the thickness of wall should cause a lowering of the initial strains or stresses. This result has not been uniformly shown in the present experiments. Exceptions may be noted in the earlier stages of dismantling the breech and the breech middle sections. In these cases it would appear that the metal near the surface of the bore was overcompressed by the treatment, and local strains were produced which became manifest when a part of the metal was removed.

To explain the application of the formulas we may take, for example, the breech section before annealing.

Stress Curves for the State of Rest.—Taking the measured compression, 71,260 pounds, on the diameter, 3.81 inches, as a basis for constructing the "deduced" curve of stresses, we first find the corresponding compression at the surface of the bore from equation (6), in which

$$r = R_0 = 1.8,\ r_1 = 1.905,\ R_1 = 4.86,\ \rho_1 = 71260.$$

Then:

$$\rho_0 = \frac{1.0647 - 0.15898 - 2.0695}{1.0647 - 0.15898 - 1.5446}\rho_1 = \frac{1.41228}{1.16378} \times 71260 = 86477 \text{ lbs.}$$

Next, applying equations (3) and (2) with ρ_0 given, we find:

$$P_u' = \frac{3 \times 20.38}{100.96 - 43.41}\rho_0 = \frac{61.14}{57.55} \times 86477 = 91870 \text{ pounds.}$$

$$\theta_u = a\,P_u = 0.70997 \times 91870 = 65225 \text{ pounds.}$$

These latter values express the theoretical condition, assumed only for auxiliary purposes, that, having a com-

pression of 71,260 pounds at the intermediate radius, 1.905 inches, an applied interior pressure of 91,870 pounds would produce throughout the whole wall of the cylinder an uniform tension of 65,225 pounds per square inch.

The remaining points of the deduced curve of stresses for the state of rest are now derived by equation (5). Having $\theta_u = 65,225$ and $P_u = 91,870$, we find:

$$\rho = 55488 - \frac{459970}{r^2}$$

in which, by substituting the several values of r, there results:

$$\left.\begin{aligned} D_0 &= 3.6,\ R_0 = 1.8: && \rho = 55488 - 141965 = -86477 \\ d &= 3.81,\ r = 1.905: && \rho = 55488 - 126750 = -71260 \end{aligned}\right\}\text{(Proof.)}$$

$$d = 4.41,\ r = 2.205: \quad \rho = 55488 - 94604 = -39116$$

&c., &c.,

as given in table A and shown on the accompanying plate 6.

The "deduced" stress curves for the state of rest in the remaining sections considered are derived in a similar manner. In each case the measured stress which is taken as a basis and so forms a common point on both the measured and deduced curves of stress is designated (see table and plate 6) by figures in parentheses, as, for example (75,000) in the breech middle section, (59,910) in the muzzle middle section, and so on.

Resistance to Interior Pressure.—The limit of elastic resistance of the metal under extension will be taken as before stated, $\theta = 60,000$. The value of P_0 will then depend upon the condition that this limit shall not be exceeded at any point. By a comparison of the measured and deduced stress curves for the state of rest, or, if need be, by a preliminary computation, the most dangerous measured stress—that is to say, the one which, under the action of an interior pressure, would be the first to reach the limit, $\theta = 60,000$, can readily be selected. Consequently the points which must be taken upon which to base the value of P_0 for the several sections are selected and designated (see table) by

underlining the critical measured stress; for example, <u>42920</u> on the diameter 9.54 inches in the breech section, and so on. In each case it is seen from the table that the corresponding stress in action is 60,000 pounds, while the stresses on other diameters are less than this; hence the condition is fulfilled.

Taking again the breech section (second stage) before annealing as an example of the method of computation, the elastic resistance of the section and the stresses on given diameters for the state of action are derived as follows:

The measured stress which in this section will first reach the limit, 60,000, is $\theta = 42{,}920$ on the diameter, 9.54 inches. The increase of stress allowable on this diameter in passing from the state of rest to action is therefore:

$$\theta = 60000 - 42920 = 17080 \text{ pounds.}$$

The corresponding value of P_0 is then found from (4), with $r = 4.77$.

$$\theta = 17080 = 0.32602\ P_0 \quad \therefore \quad P_0 = 52390 \text{ pounds.}$$

The interior pressure being thus determined, equation (4) is further applied to determine the *increase* of stress at other given radii. For this purpose it is convenient to reduce it to the form by substituting known values:

$$\theta = 5553 + \frac{262300}{r^2}$$

in which, by substituting the several values of r, we obtain the increase of stress for that radius, and, taking the algebraic sum of this result and the measured stress at the same point (at rest), we have finally the stress pertaining to the applied interior pressure, $P_0 = 52{,}390$ pounds. Thus:

		Increase.	Measured.	θ (action).
$d = 3.81,\ r = 1.905:$	$\theta = 5553 +$	$72280 = 77833$	$- 71260 =$	$+ 6573$ pounds.
$d = 4.41,\ r = 2.205:$	$\theta = 5553 +$	$53949 = 59502$	$- 56800 =$	$+ 2702$ "
*	*	* *	* *	*
$d = 9.54,\ r = 4.77:$	$\theta = 5553 +$	$11528 = 17080$	$+ 42920 =$	$+ 60000$ "
				(Proof.)

as given in table A and shown on the accompanying plate 6.

The radius of the neutral circle of stress for each section has been computed by (7) and is noted in the table.

TABLE A.

Measured and Deduced Stresses for the State of Rest and Action.

BEFORE ANNEALING.

Breech section, second stage. Original diameters, $\begin{cases} D_0 = 3.34 \text{ inches.} \\ D_1 = 9.77 \text{ inches.} \end{cases}$

Diameters.	State of rest—stresses.		State of action.		
	Measured.	Deduced.	Pressure.	Stresses.	
Inches.	*Pounds per sq. inch*	*Pounds per sq. inch*	*Pounds per sq. inch.*	*Pounds per sq. inch.*	
Bore, 3.6	....	— 86,477		+ 34	Thickness of section in calibers, 0.85.
3.81	— 71,260	—(71,260)		+ 6,573	
4.41	— 56,800	— 39,116		+ 2,702	
5.05	— 30,000	— 16,658		+ 1,694	
5.70	— 2,370	— 1,142		+ 35,477	
*					
6.30	+ 14,290	+ 9,132	52,390 (elastic resistance).	+ 46,278	
6.95	+ 23,960	+ 17,396		+ 51,235	
7 57	+ 32,900	+ 23,382		+ 56,762	
8.20	+ 35,400	+ 28,125		+ 56,557	
8.82	+ 36,700	+ 31,837		+ 55,740	
9.54	+ 42,900	+ 35,272		+ 60,000	Elastic limit.
Exterior, 9.72	....	+ 36,014		....	

* Neutral point, $d = 5.76$.

Breech middle section, second stage. Original diameters, $\begin{cases} D_0 = 2.80 \text{ inches.} \\ D_1 = 8.68 \text{ inches.} \end{cases}$

Bore, 3.20	— 78,280	— 90,721		+ 21,115	Thickness of section in calibers, 0.81.
3.38	— 75,000	—(75,000)		+ 14,789	
4.02	— 42,910	— 35,169		+ 22,595	
4.64	— 10,670	— 11,209		+ 40,146	
*					
5 26	+ 7,410	+ 4,791	59,350 (elastic resistance).	+ 48,450	
5.90	+ 18,560	+ 16,304		+ 52,566	
6.50	+ 28,380	+ 24,159		+ 57,587	
7.08	+ 34,320	+ 29,934		+ 60,000	Elastic limit.
7.65	+ 35,490	+ 34,378		+ 58,454	
8.24	+ 30,760	+ 38,041		+ 51,485	
Exterior, 8.38	+ 31,330	+ 38,799		+ 51,593	

* Neutral point, $d = 5.04$.

Muzzle middle section, second stage. Original diameters, $\begin{cases} D_0 = 2.80 \text{ inches.} \\ D_1 = 6.44 \text{ inches.} \end{cases}$

Bore, 3.20	— 65,300	— 77,348		+ 670	Thickness of section in calibers, 0.45.
3.38	— 59,910	—(59,910)		+ 56	
4.02	— 13,430	— 15,737	31,316 (elastic resistance).	+ 31,328	
*					
4.64	+ 19,070	+ 10,838		+ 54,679	
5.26	+ 30,500	+ 28,583		+ 60,000	Elastic limit.
5.90	+ 22,630	+ 41,352		+ 47,734	
Exterior, 6.06	+ 24,510	+ 43,930		+ 48,726	

* Neutral point, $d = 4.354$.

TABLE A—Continued.

BEFORE ANNEALING.

Muzzle section, third stage. Original diameters, $\begin{cases} D_0 = 2.80 \text{ inches.} \\ D_1 = 5.39 \text{ inches.} \end{cases}$

Diameters.		State of rest—stresses.		State of action.		
		Measured.	Deduced.	Pressure.	Stresses.	
	Inches.	*Pounds per sq. inch.*	*Pounds per sq. inch.*	*Pounds per sq. inch*	*Pounds per sq. inch.*	
Bore,	3.2	....	— 36,748	16,060 (elastic resistance).	+ 14,784	Thickness of section in calibers, 0.22.
	3.35	— 26,000	—(26,000)		+ 21,900	
	*					
	3.90	— 1,925	+ 3,378		+ 36,049	
	4.46	+ 28,600	+ 22,836		+ 60,000	Elastic limit.
Exterior,	4.60	....	+ 26,808		....	

* Neutral point, $d = 3.82$.

AFTER ANNEALING.

Breech section, third stage. Original diameters, $\begin{cases} D_0 = 3.34 \text{ inches.} \\ D_1 = 9.77 \text{ inches.} \end{cases}$

Bore,	3.6	— 29,170	— 30,905	52,015 (elastic resistance).	+ 60,000	Elastic limit.
	3.81	— 25,200	—(25,200)		+ 55,119	
	4.41	— 31,290	— 13,164		+ 30,330	Thickness of section in calibers, 0.75.
	5.05	— 18,120	— 4,752		+ 30,443	
	*					
	5.70	— 790	+ 1,058		+ 38,749	
	6.30	+ 9,048	+ 4,906		+ 42,613	
	6.95	+ 16,620	+ 8,002		+ 45,378	
	7.57	+ 19,220	+ 10,243		+ 44,497	
	8.20	+ 20,600	+ 12,020		+ 43,119	
	8.82	+ 21,500	+ 13,410		+ 41,860	
Exterior,	9.00	+ 18,500	+ 13,761		+ 38,315	

* Neutral point, $d = 5.562$.

Muzzle section, third stage. Original diameters, $\begin{cases} D_0 = 2.80 \text{ inches.} \\ D_1 = 5.38 \text{ inches.} \end{cases}$

Bore,	3.2	....	— 20,254	24,920 (elastic resistance).	+ 59,710	
	3.35	— 14,330	—(14,330)		+ 60,000	Elastic limit.
	*					
	3.90	— 3,460	+ 1,861		+ 55,467	Thickness of section in calibers, 0.22.
	4.46	+ 10,100	+ 12,586		+ 58,825	
Exterior,	4.60	....	+ 14,676		....	

* Neutral point, $d = 3.82$.

The Possible Maximum Resistance of the Sections.—Suppose the initial tension curve to be such as is required by theory to give a maximum resistance, several propositions may be stated :

1st. The point of critical strain may always be taken at the surface of the bore where the compression at rest or the

extension in action cannot exceed the elastic limit of the metal.

2d. To make the resistance to interior pressure a maximum in any cylinder, the state of initial tension should be such that when the pressure acts from within the whole thickness of metal in the wall should be, as nearly as practicable, uniformly strained to the elastic limit of the metal.

3d. If ρ and θ be taken equal and the compression of bore carried to the limit ρ, there is but one thickness of cylinder (0.65 caliber, nearly)* for which a condition of uniform strain in action equal to the elastic limit of the metal can be attained.

4th. For cylinders of greater thickness than 0.65 caliber a state of uniform strain in the wall will be reached in action and passed before the elastic limit of the metal is attained, and with increasing pressure this limit will be fully reached only at the surface of the bore, thus determining the limit of pressure. For such cylinders the best conditions of resistance will be obtained by utilizing the full limit of compression of the metal in the initial tension.

5th. But for cylinders of less thickness than 0.65 caliber a state of uniform strain in action equal to the elastic limit of the metal can be attained with a compression of bore less than the limit ρ. The thinner the cylinder the less should be the initial compression imposed. It follows that the possible maximum resistance of such cylinders will be obtained by adjusting the initial compression within limits. If the full limit of initial compression were given, the elastic limit of the metal would be reached in action at the exterior of the cylinder sooner than at the bore.

6th. As a consequence, also, of the preceding, the resistance of cylinders of less thickness than 0.65 caliber, treated by interior cooling, should be directly proportional to the thickness. This treatment gives the means of imparting the greatest resistance so far known to such cylinders.

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*See Appendix B, "Gun Making" and "Modern Gun Construction and Breech Mechanism," Congress of Engineers, 1893.

7th. When one point of the initial tension curve is given (either an assigned or measured value of ρ) the curve will be fixed, as has been illustrated in the examples worked out. It is important to observe that this curve as defined and laid down is, barring the presence of local strains in the metal, that which should be naturally formed under the conditions of equilibrium between the positive and negative strains in the wall of the cylinder at rest. This equilibrium must exist, and the curve as defined fulfills this condition, since it is dependent upon it. The straight line, representing the state of uniform strain in action, used in every case as the datum line for the initial tension curve, is dependent upon the condition of equilibrium between the pressure and the elastic strains in the metal. That line, however, is the initial tension curve itself in a particular position. On the withdrawal (supposed) of the force P the right line falls to the position of the initial tension curve, having lost nothing of its property to express the equilibrium of the forces which cause it to exist. This being, then, the only curve which can be formed under the circumstances, and since the value of ρ cannot exceed the given elastic limit, it may be seen why in cylinders thicker than 0.65 caliber the conditions of maximum pressure and uniform strain to the elastic limit of the metal in action cannot exist together. An initial tension curve, starting with the limit ρ at the bore and having higher strains than the natural curve toward the exterior, might be laid down which would become a straight line with P increased sufficiently to stretch the bore to the elastic limit, but such an initial tension curve is not attainable in practice.

To compute the possible maximum resistance of the present sections of cylinders we will take, as before, the conservative limits, $\theta = 60{,}000 = \rho$. The breech (after annealing) and the breech middle sections are respectively 0.75 and 0.81 caliber in thickness. Their maximum resistance will therefore depend upon the assumption that the bore is initially compressed to the limit ρ at rest and extended to the

limit θ in action, and its value will be found from equation (1) (Appendix B, "Gun Making"); whence

Breech: $$P = \frac{3\,(R_1^2 - R_0^2)}{4\,R_1^2 + 2\,R_0^2}(\rho + \theta) = \frac{51.03}{87.48} \times 120000 =$$

70000 pounds per square inch.

Breech middle: $P = \dfrac{44.99}{75.34} \times 120000 = 71652$ pounds per square inch.

The muzzle middle and muzzle sections are less than 0.65 caliber thickness, being respectively 0.45 and 0.22 caliber. The desired initial compression, or that value of ρ, in terms of the limit θ, which will cause the wall to be uniformly strained to 60,000 pounds per square inch when the limit of interior pressure is reached, is found by combining equations (1) and (2) of the work cited; whence

$$\rho = \left[\frac{4\,R_1^2 + 2\,R_0^2}{3\,(R_1^2 - R_0^2)a} - 1\right]\theta \qquad (8)$$

From which we find:

Muzzle middle: $\rho = 0.6769 \times 60000 = 40614$
Muzzle: $\rho = 0.3174 \times 60000 = 19046$

These reduced values of ρ being given, the maximum resistance will be found by applying equation (1) as for the other sections. Then

Muzzle middle: $P = \dfrac{19.8627}{41.8436}(40614 + 60000) = 47650$ pounds per square inch.

Muzzle: $P = \dfrac{8.19}{26.28}(19046 + 60000) \doteq 24634$ pounds per square inch.

The value 24,634 for the muzzle section is less than 24,920, which was computed, from the most dangerous one of the actually measured stresses, to be the resistance after annealing. This slight discrepancy is due to the irregularities of

the curve of measured stresses and that there is no measured stress for the exterior surface, where, as every indication points, the critical strain should actually be located. It will be observed that the curve of deduced stress at rest indicates a stress of 14,676 pounds at the exterior surface. Taking the latter to govern the resistance, we find, from equation (4), $P_0 = 24{,}167$. It may be said, therefore, that the probable resistance, based upon an extension limit of 60,000 pounds as taken, lies between 24,167 and 24,634 (theoretical maximum) instead of being 24,920.

Similar conditions are also present in the breech and muzzle sections before annealing, and the values given for them in table A and drawing should probably be reduced in the same proportion, or about 3 per cent. This reduction is made in the following table, which gives a comparison of the resistance of these sections and those of corresponding dimensions in the built-up field gun as now made. It must be observed, however, that in the field gun the tube is not hooped in the two forward sections.

Comparative Resistance of Initial Tension Cylinders and the 3.2-inch Built-up Field Gun.

Resistance, estimated.	Breech section.	Breech mid-section.	Muzzle mid-section.	Muzzle section.
	Pounds per sq. inch.	*Pounds per sq. inch.*	*Pounds per sq. inch.*	*Pounds per sq. inch.*
Initial tension cylinder. On measured stresses. Before annealing	50,818	59,350	31,316	15,578
Initial tension cylinder. On measured stresses. After annealing	52,015	....	....	24,167
Initial tension cylinder. Theoretical maximum	70,000	71,652	47,650	24,634
3.2-inch field gun computed resistance	38,250	41,030	21,730	13,995

Conclusions.—The graphic representation of the curves of stress, &c., on the accompanying plate 6 affords the best means of judging the results of the treatment of the forging. The close accordance of the measured and deduced curves of stress in the forging after treatment is not accidental, because, as previously stated, both curves depend upon the

equilibrium of the strains in the forging, and by construction they have one point in common. Their further coincidence, therefore, is evidence of the uniformity of results obtained by the treatment. The somewhat marked irregularity of the measured stresses near the bore in the breech section, both before and after annealing, has led to the construction of two deduced curves, of which it will be seen that the one marked No. 2 coincides most nearly with the measured curve. This No. 2 is based upon the measured compression on the second circle from the bore. There is apparent evidence in this section that the contractile force of the outer layers of metal in cooling was sufficient to over-compress the metal near the bore.

The strains engendered in all the sections by the interior cooling were apparently unnecessarily severe, and tended to produce too great a strain of tension toward the exterior for economy of resistance to interior pressure. Thus, in all of the sections, before annealing, it is seen that the curve of stress in action departs considerably from a horizontal line, and the limit of stress in action is reached first at or near the exterior surface.* Of the four, however, the breech middle section is exceptionally well disposed.

It is important to note the general resemblance of the measured curves of stress in the four sections as showing the regularity of the cooling treatment throughout the length of the forging, and that an inspection of the end sections would have disclosed the condition of initial tension in the whole forging. This forging, as shown on the drawing, had marked irregularity of sectional dimensions, yet the degree of initial tension in the several sections is in general proportional to the thickness of the section, and there is no general abnormal distortion of either thin or thick sections.

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*The position of the stress curve for the state of action is necessarily influenced by the selection of the value $\theta = 60{,}000$. If this value had been taken equal to 68,000, as given in the report of physical qualities of the metal before quoted, the stress curves in action would be considerably more elevated next the bore, and the estimated values of P_0 would be correspondingly increased.

This result was, however, to be expected, inasmuch as the theoretical curve of initial tension depends upon the thickness of wall in calibers, and the actual curve evidently obeys the same law.

This experiment leaves no room to doubt that initial tension strains of as great intensity as are desirable can be produced in a hollow forging by interior cooling, and if these strains should be more than needed they can be reduced by annealing. The effect of the subsequent annealing in the present case was beneficial, particularly in the muzzle section, which now shows the peculiarly interesting case of a resistance to interior pressure which closely approximates the possible maximum. The ordinates of the stress curve in action are all nearly equal and differ but little from the limit of 60,000 pounds.

Without disparagement to the built-up, hooped gun, which has proved to be excellent, it may be said that the apparent superiority of a gun made of a single forging, with initial tension produced by interior cooling, rests not only upon claims for reduced cost and increased longitudinal stiffness, but also for increased tangential strength in every section where the actual thickness of wall is insufficient in practice for the division of the built-up gun into as many as four layers, since this number of layers is in general required in that construction to enable the bore to be worked through the double limit of elastic movement.

Inasmuch as the walls of built-up, hooped guns below 10 or perhaps 8 inches caliber cannot be conveniently divided into four layers, and this division, moreover, can only be applied in the thicker portions (*i. e.*, the reinforce), the conclusion from the theoretical standpoint, at least, is that an equality of tangential strength will exist under the two modes of construction for the reinforce of guns of 8 or 10 inches caliber and upwards; but for guns of smaller caliber and for the chase portions of all guns the greater tangential strength will pertain to the single forging with initial tension produced by interior cooling.

THE LATITUDE-VARIATION TIDE.*

BY

ALEXANDER SMYTH CHRISTIE.

[Read before the Mathematical Section May 23, 1895. The non-mathematical part was read before the Society May 11, 1895.]

I.

The Derivation of the Formulæ.

Let

$$\left.\begin{aligned} H &= h + \sum_r (c_r \cos i_r t + s_r \sin i_r t) \\ &= h + \sum_r a_r \cos (i_r t - \varepsilon_r) \end{aligned}\right\} \quad (1)$$

be the height of the surface of the sea at time t above any datum plane, then for a series of ν observations at equal time intervals τ we have, t denoting the middle of the series,

$$H_0 = h + \sum_r \left\{ c_r \cos i_r \left(t - \frac{\nu - 1}{2} \tau \right) + s_r \sin i_r \left(t - \frac{\nu - 1}{2} \tau \right) \right\}$$

$$H_1 = h + \sum_r \left\{ c_r \cos i_r \left(t - \frac{\nu - 3}{2} \tau \right) + s_r \sin i_r \left(t - \frac{\nu - 3}{2} \tau \right) \right\}$$

$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

$$H_{\nu - 1} = h + \sum_r \left\{ c_r \cos i_r \left(t + \frac{\nu - 1}{2} \tau \right) + s_r \sin i_r \left(t + \frac{\nu - 1}{2} \tau \right) \right\}.$$

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* General W. W. Duffield, Superintendent of the United States Coast and Geodetic Survey, has very courteously granted me permission to publish the data given below, and has also favored me with copies of several papers on file in his office prepared by me while engaged in the search for this tide. A paper containing the full discussion is reported to him by his subordinates as not found.

Summing, dividing by ν, and putting

$$\frac{1}{\nu}(H_0 + H_1 + \ldots + H_{\nu-1}) = T,$$

$$\frac{1}{2} i_r \tau = \beta_r, \quad \frac{\sin \nu \beta_r}{\nu \sin \beta_r} = u_r,$$

$$u c = C, \quad u s = S, \quad u a = A,$$

we obtain

$$\left.\begin{aligned} T &= h + \sum_r (C_r \cos i_r t + S_r \sin i_r t) \\ &= h + \sum_r A_r \cos (i_r t - \varepsilon_r) \end{aligned}\right\} \qquad (2)$$

For every value of t employed in the numerical summations the terms in (2) arising from tides other than the one sought may be computed and removed whenever their defining elements are known, but the process would be very laborious, and for the present purpose is unnecessary.

Let m be a positive integer, j the speed and $m\nu\tau$ the complete period assumed for the tide sought, and put

$$\sum_r (C_r \cos i_r t + S_r \sin i_r t) = \sum_r \theta_r,$$

where i_r no longer includes j; then (2) becomes

$$h + C_j \cos j t + S_j \sin j t + C_{2j} \cos 2 j t + \ldots - (T - \sum_r \theta_r) = 0.$$

Putting in this successively $j t = -\frac{m-1}{m}\pi, -\frac{m-3}{m}\pi, \ldots \ldots + \frac{m-1}{m}\pi$, where $\pi = 180°$, we have

$$\begin{array}{llll} h & C_j & S_j & C_{2j} \end{array}$$

$$1 + \cos\frac{1-m}{m}\pi + \sin\frac{1-m}{m}\pi + \cos 2\frac{1-m}{m}\pi + \ldots - (T - \sum_2 \theta_r)_{\frac{1-m}{2}} = 0$$

$$1 + \cos\frac{3-m}{m}\pi + \sin\frac{3-m}{m}\pi + \cos 2\frac{3-m}{m}\pi + \ldots - (T - \sum_r \theta_r)_{\frac{3-m}{2}} = 0$$

$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

$$1 + \cos\frac{m-1}{m}\pi + \sin\frac{m-1}{m}\pi + \cos 2\frac{m-1}{m}\pi + \ldots - (T - \sum_r \theta_r)_{\frac{m-1}{2}} = 0;$$

of which the least square solution is

$$\left.\begin{aligned} h &= h' + h'' \\ C_{pj} &= C_{pj}' + C_{pj}'' \\ S_{pj} &= S_{pj}' + S_{pj}'' \end{aligned}\right\}, \tag{3}$$

where

$$h' = \frac{1}{m} \sum_{k} T_k$$

$$C_{pj}' = (-)^p \frac{2}{m} \sum_{k} T_k \cos p\,(2k+1)\frac{\pi}{m}$$

$$S_{pj}' = (-)^p \frac{2}{m} \sum_{k} T_k \sin p\,(2k+1)\frac{\pi}{m}$$

$$h'' = -\sum_{r} c_r \frac{\sin m\nu\beta_r}{m\nu \sin \beta_r}$$

$$C_{pj}'' = -\cos p\frac{\pi}{m} \;.\; \sum_{r} c_r v_r \sin \nu\beta_r$$

$$S_{pj}'' = -\sin p\frac{\pi}{m} \;.\; \sum_{r} s_r v_r \cos \nu\beta_r$$

$$v_r = (-)^p \frac{2 \sin m\nu\beta_r \sin \nu\beta_r}{m\nu \sin \beta_r \sin\left(\nu\beta_r - p\frac{\pi}{m}\right) \sin\left(\nu\beta_r + p\frac{\pi}{m}\right)},$$

the summations with respect to k being taken from $k = 0$ to $k = m - 1$. The probable errors are to be computed by the usual formulæ. These forms are adapted to the treatment of the observations one j-period at a time; the quantities ε_r implied in c_r and s_r must be taken for the middle of the period, and to this epoch the resulting values of C_{pj} and S_{pj} relate. We then have for the same epoch the final values

$$c_{pj} = C_{pj} \div u_{pj}\;,\; s_{pj} = S_{pj} \div u_{pj}\,,$$

$$a_{pj} = \sqrt{c_{pj}^2 + s_{pj}^2}\,,\; \varepsilon_{pj} = \tan^{-1}(s_{pj} \div c_{pj}),$$

for substitution in the form

$$\left.\begin{array}{l} c_{pj}\ cos\ p\,j\,t + s_{pj}\ sin\ p\,j\,t \\ a_{pj}\ cos\ (p\,j\,t - \varepsilon_{pj}) \end{array}\right\} \qquad (4)$$

or

expressing the j-tide of p^{th} order.

Resume equation (2): Then

$$T_0 = h + \sum_r \left\{ C_r\ cos\ i_r\left(t - \frac{N-1}{2} m\,\nu\,\tau\right) + S_r\ sin\ i_r\left(t - \frac{N-1}{2} m\,\nu\,\tau\right) \right\}$$

$$T_1 = h + \sum_r \left\{ C_r\ cos\ i_r\left(t - \frac{N-3}{2} m\,\nu\,\tau\right) + S_r\ sin\ i_r\left(t - \frac{N-3}{2} m\,\nu\,\tau\right) \right\}$$

$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

$$T_{N-1} = h + \sum_r \left\{ C_r\ cos\ i_r\left(t + \frac{N-1}{2} m\,\nu\,\tau\right) + S_r\ sin\ i_r\left(t + \frac{N-1}{2} m\,\nu\,\tau\right) \right\}$$

are N consecutive derivative ordinates T separated by a complete j-period, and hence relating to the same phase of the j-tide. Summing, putting

$$\frac{1}{N}(T_0 + T_1 + \ldots + T_{N-1}) = Q,$$

$$\frac{sin\ N\,m\,\nu\,\beta_r}{N\ sin\ m\,\nu\,\beta_r} = U,$$

$$U C = \gamma\,,\ \ U S = \sigma\,,$$

we obtain

$$Q = h + \sum_r (\gamma_r\ cos\ i_r\,t + \sigma_r\ sin\ i_r\,t)\,; \qquad (5)$$

or, putting

$$\sum_r (\gamma_r\ cos\ i_r\,t + \sigma_r\ sin\ i_r\,t) = \sum_r \varphi_r\,,$$

where i_r no longer includes j, we have

$$h + \gamma_j\ cos\ j\,t + \sigma_j\ sin\ j\,t + \gamma_{2j}\ cos\ 2\,j\,t + \ldots - (Q - \sum_r \varphi_r) = 0.$$

Writing in this successively $j\,t = -\frac{m-1}{m}\pi,\ -\frac{m-3}{m}\pi,\ \ldots$ $\ldots + \frac{m-1}{m}\pi$, we get m equations, of which the least square solution is

$$\left.\begin{aligned} h &= (h') + (h'') \\ \gamma_{pj} &= \gamma_{pj}' + \gamma_{pj}'' \\ \sigma_{pj} &= \sigma_{pj}' + \sigma_{pj}'' \end{aligned}\right\}, \tag{6}$$

where

$$(h') = \frac{1}{m} \sum_k Q_k$$

$$\gamma_{pj}' = (-)^p \frac{2}{m} \sum_k Q_k \cos p\,(2\,k + 1) \frac{\pi}{m}$$

$$\sigma_{pj}' = (-)^p \frac{2}{m} \sum_k Q_k \sin p\,(2\,k + 1) \frac{\pi}{m}$$

$$(h'') = -\sum_r c_r \frac{\sin N\,m\,\nu\,\beta_r}{N\,m\,\nu\,\sin \beta_r}$$

$$\gamma_{pj}'' = -\cos p \frac{\pi}{m} \cdot \sum_r c_r\, w_r \sin \nu\,\beta_r$$

$$\sigma_{pj}'' = -\sin p \frac{\pi}{m} \cdot \sum_r s_r\, w_r \cos \nu\,\beta_r$$

$$w_r = (-)^p \frac{2 \sin N m\,\nu\,\beta_r \sin \nu\,\beta_r}{N m\,\nu \sin \beta_r \sin\left(\nu\,\beta_r - p\frac{\pi}{m}\right) \sin\left(\nu\,\beta_r + p\frac{\pi}{m}\right)},$$

the summations with respect to k being from $k = 0$ to $k = m - 1$. The probable errors are to be computed by the usual formulæ. These forms are adapted to the treatment of the observations one section of N superposed j-periods at a time. The quantities ε_r implied in c_r and s_r must be taken for the middle of the section, and to this epoch the resulting values of γ_{pj} and σ_{pj} relate. We then have for the same epoch the final values

$$c_{pj} = (-)^{p(N+1)}\, \gamma_{pj} \div u_{pj}\,, \quad s_{pj} = (-)^{p(N+1)}\, \sigma_{pj} \div u_{pj}\,,$$

$$a_{pj} = \sqrt{c_{pj}^2 + s_{pj}^2}\,, \quad \varepsilon_{pj} = \tan^{-1}(s_{pj} \div c_{pj}),$$

for substitution in the forms (4).

Let $\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_{2r}$, or $\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_{2s+1}$, according as the number of consecutive periods or sections from which the ε's

are derived is even or odd, be the values of ε in the p^{th} term of the j-tide, as obtained from the several successive and consecutive periods or sections by the numerical process reflected in the foregoing analysis, I the time-length of a period, or section, as the case may be, and δj a correction to the assumed value of the speed, so that the corrected or true speed of the tide or inequality sought is $i = j + \delta j$; then, denoting by ε_0 the true value of ε at the middle of the series, we have for the determination of ε_0 and δj the conditional equations

$$
\begin{array}{llllll}
\varepsilon_0 & p I \delta j & & \text{or} & \varepsilon_0 & p I \delta j \\
1 & + \frac{2r-1}{2} & - \varepsilon_1 & = 0 & 1 + s & - \varepsilon_1 = 0 \\
1 & + \frac{2r-3}{2} & - \varepsilon_2 & = 0 & 1 + (s-1) & - \varepsilon_2 = 0 \\
\cdot & \cdot & \cdot & \cdot & \cdot \quad \cdot & \cdot \quad \cdot \\
1 & + \frac{1}{2} & - \varepsilon_r & = 0 & 1 + \quad 1 & - \varepsilon_s = 0 \\
1 & - \frac{1}{2} & - \varepsilon_{r+1} & = 0 & 1 \pm \quad 0 & - \varepsilon_{s+1} = 0 \\
\cdot & \cdot & \cdot & \cdot & 1 - \quad 1 & - \varepsilon_{s+2} = 0 \\
1 & - \frac{2r-3}{2} & - \varepsilon_{2r-1} & = 0 & \cdot \quad \cdot & \cdot \quad \cdot \\
1 & - \frac{2r-1}{2} & - \varepsilon_{2r} & = 0 & 1 - \quad s & - \varepsilon_{2s+1} = 0;
\end{array}
$$

whence the most probable values are

$$\varepsilon_0 = \frac{1}{2r} \sum_{k=1}^{k=2r} \varepsilon_k$$

$$\delta j = \frac{3}{p I . r (2r-1)(2r+1)} \sum_{k=1}^{k=2r} (2r - 2k + 1) \varepsilon_k$$

or

$$\varepsilon_0 = \frac{1}{2s+1} \sum_{k=1}^{k=2s+1} \varepsilon_k$$

$$\delta j = \frac{3}{p I . s (s+1)(2s+1)} \sum_{k=1}^{k=2s+1} (s - k + 1) \varepsilon_k .$$

From the weighted values of δj resulting from the treatment of the several terms of the j-tide that are sensible, a mean correction to the assumed speed, and hence a correction to the assumed period, is obtained.

The preceding formulæ, which are worked out in accordance with received principles, are those employed by me in 1892 in finding the latitude-variation tide in Penobscot bay, and they differ from those submitted to the Philosophical Society in my paper of May 21, 1892, which I had employed in 1891–'92 in finding the same tide in San Francisco bay, only in the simplifications arising from assuming the middle instant of the observations, instead of the initial instant, as the secondary time zero. In my revision of the work for publication in the Coast Survey annual volume, I employed the simplified formulæ at both stations. This transference of the secondary time zero is especially important in connection with a solution which I now proceed to develop. I early perceived its possibility, and had it under consideration when I left the Coast Survey in 1893.

When δj is null—that is to say, when the period assumed in the grouping of the observations is precisely that of the inequality sought—the amplitudes will not suffer in the summations, nor will the epochs be displaced; but when δj differs from zero the amplitudes will be diminished and the epochs advanced or retarded in the process of their derivation. It is my purpose now to determine, in this latter the general case, the corrected values of the amplitudes and epochs without having recourse to the tedious operation of redistributing the observations according to the corrected period.

In the case to be considered, namely, when δj is not null, there is in reality no j-tide, C_{pj} and S_{pj} in (3) are null, and the tide of speed $i = j + \delta j$, with its harmonics, is to be found among the terms of C_{pj}'' and S_{pj}''. We then have as the correct solution

$$0 = C_{pj}' + C_{pj}''$$

$$0 = S_{pi}' + S_{pj}'',$$

or, as a special case, when only the i-tides are sought,

$$\left.\begin{aligned}\sum_q c_{qi}\, V_{qi}\, sin\, \nu\beta_{qi} - [A - \sum_r c_r\, V_r\, sin\, \nu\beta_r] = 0 \\ \sum_q s_{qi}\, V_{qi}\, cos\, \nu\beta_{qi} - [B - \sum_r s_r\, V_r\, cos\, \nu\beta_r] = 0\end{aligned}\right\}, \tag{7}$$

where

$$A = \nu\, sec\, p\frac{\pi}{m} \,.\, \sum_k T_k\, cos\, p\,(2\,k+1)\frac{\pi}{m}$$

$$B = \nu\, cosec\, p\frac{\pi}{m} \,.\, \sum_k T_k\, sin\, p\,(2\,k+1)\frac{\pi}{m}$$

$$V_r = \frac{sin\, \nu\beta_r\, sin\, m\,\nu\beta_r}{sin\, \beta_r\, sin\left(\nu\beta_r - p\frac{\pi}{m}\right) sin\left(\nu\beta_r + p\frac{\pi}{m}\right)}$$

$$V_{qi} = \frac{sin\, \nu\beta_{qi}\, sin\, m\,\nu\beta_{qi}}{sin\, \beta_{qi}\, sin\left(\nu\beta_{qi} - p\frac{\pi}{m}\right) sin\left(\nu\beta_{qi} + p\frac{\pi}{m}\right)},$$

and i_r includes neither j nor i. The summations with respect to k are from $k=0$ to $k=m-1$. Equations (7), in which each unknown is affected by a factor of diminution, take the place of the last two series of equations given by (3) and afford by their solution the c's and s's, and hence the a's and ϵ's, for substitution in the forms (4).

In like manner we have from (6)

$$0 = \gamma_{pj}' + \gamma_{pj}''$$

$$0 = \sigma_{pj}' + \sigma_{pj}'',$$

or

$$\left.\begin{aligned}\sum_q c_{qi}\, W_{qi}\, sin\, \nu\beta_{qi} - [E - \sum_r c_r\, W_r\, sin\, \nu\beta_r] = 0 \\ \sum_q s_{qi}\, W_{qi}\, cos\, \nu\beta_{qi} - [F - \sum_r s_r\, W_r\, cos\, \nu\beta_r] = 0\end{aligned}\right\}, \tag{8}$$

where

$$E = N\nu\, sec\, p\frac{\pi}{m} \,.\, \sum_k Q_k\, cos\, p\,(2\,k+1)\frac{\pi}{m}$$

$$F = N\nu\, cosec\, p\frac{\pi}{m} \,.\, \sum_k Q_k\, sin\, p\,(2\,k+1)\frac{\pi}{m}$$

$$W_r = \frac{\sin \nu \beta_r \sin N m \nu \beta_r}{\sin \beta_r \sin \left(\nu \beta_r - p \frac{\pi}{m}\right) \sin \left(\nu \beta_r + p \frac{\pi}{m}\right)}$$

$$W_{qi} = \frac{\sin \nu \beta_{qi} \sin N m \nu \beta_{qi}}{\sin \beta_{qi} \sin \left(\nu \beta_{qi} - p \frac{\pi}{m}\right) \sin \left(\nu \beta_{qi} + p \frac{\pi}{m}\right)},$$

and i_r includes neither j nor i. The summations with respect to k are from $k = 0$ to $k = m - 1$. Equations (8) take the place of the last two series of equations given by (6), and afford by their solution the c's and s's, and hence the a's and ε's, for substitution in the forms (4).

The generality and flexibility of this solution may be remarked. The ordinary solution, when the period of the inequality is known in advance and the observations are grouped in accordance with that period, is obtained from it by putting $i = j$. The method here given applies whether the period of the inequality sought is known in advance exactly, with considerable precision, or only roughly, and I would suggest that it might prove useful in picking up inequalities when nothing is known of their periods. The transference of the secondary time zero to the midde instant of the observations preserves in both the solutions of this paper the inherent symmetry and simplicity of the forms; in the last one it effects a complete axial revolution, separating the cosine from the sine coefficients, and thus notably diminishing the labor of solution. From a theoretical point of view, the most remarkable thing about the second solution is that the j-coefficients, to which is assigned the title rôle in the formation of the normal equations, are not the quantities sought, and when the solution is effected it inures to the benefit of other coefficients—that is to say, other coefficients are thereby determined. I do not recall any other instance in mathematics where a like distinctively vicarious action appears or is noted. That this vicarious solution is logically sound may be shown in various ways. It may be made to repose upon the fact that the certain and only possible value

of the j-coefficients derivable from the equations of condition is zero, and the obvious principle that certainty is probability, namely, the highest degree of probability, a probability that excludes every alternative. Thus, wherever there is a system of n simultaneous linear equations in n unknowns, the method of least squares affords a valid transformation, which at times may facilitate their solution. Take, for example, the derivation of Fourier's integral: The problem is, first, to determine the unique, the only possible, values of the coefficients in

$$c_0 + \sum_{p=0}^{p=\infty} (c_p \cos pjx + s_p \sin pjx)$$

so that the series may be the equivalent of $\varphi(x)$ for all values of x between $-\frac{\pi}{j}$ and $+\frac{\pi}{j}$, $\varphi(x)$ being subject to the well-known limitations. Putting jx successively equal to $-\frac{m-1}{m}\pi$, $-\frac{m-3}{m}\pi$, . . . , $+\frac{m-1}{m}\pi$, we obtain

$$\begin{array}{llll} c_0 & c_1 & s_1 & c_2 \\ 1 & +\cos\frac{1-m}{m}\pi & +\sin\frac{1-m}{m}\pi & +\cos 2\frac{1-m}{m}\pi + \ldots - \varphi\left(\frac{1-m}{m}\frac{\pi}{j}\right) = 0 \\ 1 & +\cos\frac{3-m}{m}\pi & + \ldots\ldots & \ldots\ldots - \varphi\left(\frac{3-m}{m}\frac{\pi}{j}\right) = 0 \\ \cdot & \cdot & \cdot & \cdot \\ 1 & +\cos\frac{m-1}{m}\pi & + \ldots\ldots & \ldots\ldots - \varphi\left(\frac{m-1}{m}\frac{\pi}{j}\right) = 0, \end{array}$$

whence by least squares, to obtain the *unique* values, which are therefore the *most probable* values of the coefficients,

$$c_0 = \frac{1}{m}\sum_{k=0}^{k=m-1} \varphi\left(\frac{2k+1-m}{m}\frac{\pi}{j}\right)$$

$$c_p = \frac{2}{m}\sum_{k=0}^{k=m-1} \varphi\left(\frac{2k+1-m}{m}\frac{\pi}{j}\right)\cos p\,\frac{2k+1-m}{m}\pi$$

$$s_p = \frac{2}{m}\sum_{k=0}^{k=m-1} \varphi\left(\frac{2k+1-m}{m}\frac{\pi}{j}\right)\sin p\,\frac{2k+1-m}{m}\pi.$$

When m = an infinity of a higher order than $p = \infty$ these become

$$c_0 = \frac{j}{2\pi} \int_{-\frac{\pi}{j}}^{+\frac{\pi}{j}} d\,a\,\varphi\,(a)$$

$$c_p = \frac{j}{\pi} \int_{-\frac{\pi}{j}}^{+\frac{\pi}{j}} d\,a\,\varphi\,(a)\cos p\,j\,a$$

$$s_p = \frac{j}{\pi} \int_{-\frac{\pi}{j}}^{+\frac{\pi}{j}} d\,a\,\varphi\,(a)\sin p\,j\,a\,,$$

and then Fourier's integral,

$$\varphi\,(x) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} d\,a\,\varphi\,(a) \int_{-\infty}^{+\infty} d\,\beta\cos\beta\,(a-x)$$

follows in the usual way. Thus a known (*) special device of solution is referred to a general principle, and Fourier's integral, with all its consequences, is derived from the calculus of probabilities.

II.

Results of the Application of the Formulæ to the Tides of San Francisco and Penobscot Bays.

At the close of the official day of December 18, 1891, Dr. T. C. Mendenhall, at that time superintendent of the United States Coast and Geodetic Survey, informed me that Professor Simon Newcomb had suggested to him that the Survey should endeavor to find the tide corresponding to the latitude-variation then under discussion by astronomers, and to which Dr. S. C. Chandler had then recently assigned a

*See Byerly (Wm. E.) An elementary treatise on Fourier's series, etc., 8°, Boston, Ginn & Co., 1893, chapter II, which I have consulted since obtaining my results.

period of 427 days. After a brief consultation as to the tidal observations available, the superintendent directed me, as chief of the tidal division, to make a rapid preliminary search for the tide, with the understanding that if its existence were once established a more careful determination could be made at our convenience. I made an analysis of the subject that evening, the work of reduction of the observations began next morning, and on February 13, 1892, I passed to the superintendent, in writing, the defining elements of the latitude-variation tide, as derived from the observations made at the Coast Survey mareograph stations in the immediate vicinity of San Francisco, Cal., namely, at Fort Point, latitude 37° 48′.4, longitude 122° 28′.2, from February 5, 1856, to February 15, 1870, and at Sausalito (formerly Saucelito), latitude 37° 50′.5, longitude 122° 28′.5, from February 19, 1877, to March 2, 1891, in the form

$$a_1 \cos(it - \epsilon_1) + a_2 \cos(2it - \epsilon_2),$$

with

$$a_1 = \overset{ft.}{0.066} = \overset{in.}{0.79} = \overset{mm.}{20}, \quad \epsilon_1 = 82°,$$

$$a_2 = \overset{ft.}{0.038} = \overset{in.}{0.46} = \overset{mm.}{12}, \quad \epsilon_2 = 16°,$$

$$i = 0°.03428 \text{ per mean solar hour},$$

$$\text{Period} = \overset{d.}{437.6} \text{ days},$$

t reckoned from 0^h, February 5, 1856, San Francisco mean local civil time.

I then proceeded to bring into the reduction seven more years at Fort Point, thus completing at the two stations, which are connected by a line of spirit-levels and may be regarded as a single station, a 35-year series extending from February 5, 1856, to March 2, 1891, constituting 30 consecutive periods of 427 days each; and I revised those portions of the whole work where the condition of the observations and the inferior character of the tabulations and daily summations, made many years before, were most favorable to the occurrence of error. The result was a modification to

$$a_1 = \overset{ft.}{0.051} = \overset{in.}{0.61} = \overset{mm.}{15.5},$$
$$\epsilon_1 = 98° \pm 24°,$$
$$\text{Period} = \overset{d.}{437.6} \pm \overset{d.}{2.0};$$

and I reserved the second term for further consideration. Thus far the assumed period, in conformity with which the observations had been distributed into groups, was the then Chandler period of 427 days. In this distribution (see the formulæ) $\tau = 1^h$, $\nu = 1281$, $m = 8$, $N = 6$. I computed and applied all the corrections for imperfect elimination of other tides (the C'' and S'' terms in (3) and the γ'' and σ'' terms in (6)), finding them sensible for the solar annual and semi-annual, the lunar declinational diurnal, and the lunar semi-diurnal.

On communicating these revised results to the superintendent, he directed me to make two other distributions of the same series. I selected the periods 440 days and 456 days. In the 440-day distribution $\tau = 1^h$, $\nu = 1320$, $m = 8$, $N = 5$, and I had to apply corrections for the solar annual and semiannual, the lunar declinational diurnal, and the larger lunar elliptic diurnal. In the 456-day distribution $\tau = 1^h$, $\nu = 1368$, $m = 8$, $N = 4$, and I had to apply corrections for the solar annual and semiannual and the lunar semidiurnal. The results for a and ϵ from the several independent sections of each distribution are brought together in the following table:

No. of section.	427-day distribution.		440-day distribution.		456-day distribution.	
	a.	ε.	a.	ε.	a.	ε.
	ft.	°	ft.	°	ft.	°
1	0.0784	77.4	0.0644	187.3	0.0812	150.8
2	413	134.4	668	194.1	528	51.2
3	307	274.4	431	180.0	458	113.1
4	740	239.0	752	198.2	465	10.1
5	0.0306	285.0	079	*[33.7]	628	— 11.8
6	....	....	0.0785	122.1	279	— 160.2
7	....	....	....	....	0.1250	— 230.3

* Rejected for indetermination.

From these I obtained

	427-day distribution.	440-day distribution.	456-day distribution.
Period	$\overset{d.}{437.6} \pm \overset{d.}{2.0}$	$\overset{d.}{437.0} \pm \overset{d.}{1.0}$	$\overset{d.}{437.7} \pm \overset{d.}{1.9}$
a_1	$\overset{ft.}{0.051} \pm \overset{ft.}{0.007}$	$\overset{ft.}{0.056} \pm \overset{ft.}{0.007}$	$\overset{ft.}{0.063} \pm \overset{ft.}{0.008}$
ε_1	$219° \pm 24°$	$203° \pm 12°$	$170° \pm 24°$

The date to which ε_1 relates is 0^h, July 1, 1854, civil reckoning. The three distributions covered the period July 1, 1854, to March 2, 1891, 38 years and 8 months. I took the mean of the three and wrote for result

$$a_1 \cos (i\,t - \varepsilon_1),$$

with

$$a_1 = \overset{ft.}{0.057} = \overset{in.}{0.68} = \overset{mm.}{17.3}$$
$$\qquad \pm 7 \qquad \pm 9 \qquad \pm 2.2$$

$$\varepsilon_1 = 197° \pm 20$$

$$i = 0°.03429 \pm 13$$

$$\text{Period} = \overset{d.}{437.4} \pm 1.7,$$

t reckoned in hours from 0^h, July 1, 1854, San Francisco mean local civil time. The superintendent communicated these results to the National Academy of Sciences at its session in Washington in April, 1892, and I included them in a paper read before the Philosophical Society on May 21, 1892.

Immediately upon the adjournment of the National Academy I began the reduction of the tidal observations made at the Coast Survey mareograph station at Pulpit harbor, Penobscot bay, Maine, 1870–1888, and distributed them into three independent consecutive sections of five 440-day periods each, extending from 0^h, January 22, 1870, to 23^h, February 16, 1888. The preliminary results, brought out without

correcting for imperfect elimination of other tides, orally reported to the superintendent May 21, 1892, and communicated to the Philosophical Society in my paper that evening, are given below in the recapitulation.

About February, 1893, I resumed work on this tide, revised the computations, and rewrote my official report for publication in the Coast Survey annual volume. It was practically finished when I was forced to resign, April 18, 1893. This paper contained the development of the formulæ of reduction, a description of the data, the record of spirit-levels at the mareograph stations, the derivative ordinates (eight to each period), like ordinates for each section, tables of the computed corrections, the corrected results, and suggestions for the further prosecution of the work in a less expensive manner. I have not succeeded in having this paper produced, nor the one of which it was a revision; the data which I now have are too scanty and fragmentary to enable me to rewrite it, even if I had the time to give to it. I have lately, however, at great inconvenience to myself, gone over everything relative to the San Francisco tides accessible to me. There is, in my opinion, a second term of the latitude-variation tide, with double speed and half period, and with a range about half that of the first term, but the use of the records of the tidal division would be necessary to enable me to determine its period without ambiguity. It may also be remarked that the ordinates of the 440-day distribution at San Francisco can be easily thrown into three consecutive twelve-year periods and superposed, with a view to bringing out a tide corresponding to the twelve-year term of the latitude-variation discovered by Dr. Chandler.

The revised results follow. The epochs are given for the corresponding date, which is the mean local civil date of the middle of the series treated. The Julian dates are local astronomical. All these dates, with the other quantities, are given with greater precision than the nature of the results, if they were to stand alone, would warrant; but they are for comparison with other results. The San Francisco mareo-

graph station is still running, and another section can be very soon added there. The Governors Island, Sandy Hook, and Fort Hamilton series can be treated as a single series nearly half a century long, and doubtless many more will be reduced both in this and in foreign countries. Since the non-rigidity of the earth is not known, the divergence of the axes of rotation and figure have been computed, on the supposition that the earth is rigid, for comparison with the results from astronomical observations. In this way we may come to have a measure of the non-rigidity.

Recapitulation.

Revised Results at San Francisco, California.

Mean position of stations $\begin{cases} \text{latitude, } 37^\circ\ 49'.5. \\ \text{longitude, } 122^\circ\ 28'.4. \end{cases}$

	427-day distribution.	440-day distribution.	456-day distribution.
Date ...	Aug. 18, 1873	July 25, 1872	Dec. 22, 1871
Period...	$437.6^{d.} \pm 2.3^{d.}$	$437.0^{d.} \pm 1.0^{d.}$	$437.7^{d.} \pm 2.0^{d.}$
a_1 ...	$0.051^{ft.} \pm 0.007^{ft.}$	$0.056^{ft.} \pm 0.007^{ft.}$	$0.063^{ft.} \pm 0.008^{ft.}$
ε_1 ...	$207^\circ \pm 15^\circ$	$173^\circ \pm 7^\circ$	$349^\circ \pm 14^\circ$
ε_1 reduced to mean date..	$120^\circ \pm 15^\circ$	$125^\circ \pm 7^\circ$	$124^\circ \pm 14^\circ$

Giving these three distributions of substantially the same data equal weights, and taking for the probable error of the mean simply the mean of the probable errors, as not too great, we obtain

Civil date = September 21, 1872.

Julian date = 2405058

$$\text{Period} = 437.4^{d.} \pm 1.8^{d.}$$

$$a_1 = \underset{\pm 7}{0.057^{ft.}} = \underset{\pm 8}{0.68^{in.}} = \underset{\pm 2.1}{17.4^{mm.}} = \underset{\pm 2}{0''.17}$$

$$\varepsilon_1 = 123^\circ \pm 12^\circ,$$

and may write the latitude-variation tide at San Francisco

$$\left.\begin{matrix} \overset{mm.}{17.4} \\ \pm 2.1 \end{matrix}\right\} \cos \left\{ \frac{360^\circ}{437.4 \pm 1.8}\, t - \begin{pmatrix} 123^\circ \\ \pm 12 \end{pmatrix} \right\},$$

t reckoned in days from September 21, 1872.

Minimum, 1872, July 14 ± 15.
Maximum, 1873, February 18 ± 15.

Preliminary Results at Pulpit Harbor, Maine.

Position of station $\begin{cases} \text{latitude, } 44^\circ\ 09'. \\ \text{longitude, } 68^\circ\ 53'. \end{cases}$

Civil date = February 3, 1879

Julian date = 2407384

Period $= \overset{d.}{424.9} \pm \overset{d.}{2.2}$

$$a_1 = \begin{matrix} \overset{ft.}{0.041} \\ \pm 10 \end{matrix} = \begin{matrix} \overset{in.}{0.49} \\ \pm 12 \end{matrix} = \begin{matrix} \overset{mm.}{12.5} \\ \pm 3.0 \end{matrix} = \begin{matrix} 0''.12 \\ \pm 3 \end{matrix}$$

$\epsilon_1 = 41^\circ \pm 8^\circ$,

and the tide may be written

$$\left.\begin{matrix} \overset{mm.}{12.5} \\ \pm 3.0 \end{matrix}\right\} \cos \left\{ \frac{360}{424.9 \pm 2.2}\, t - \begin{pmatrix} 41^\circ \\ \pm 8 \end{pmatrix} \right\},$$

t reckoned in days from February 3, 1879.

Minimum, 1878, August 24 ± 10.
Maximum, 1879, March 24 ± 10.

Combination of the Results at San Francisco and Pulpit Harbor.

In combining the results I give the two stations the same weight. The great source of error at both stations was variations in the altitude of the tide-staff zero, the amount of

which was not determined by levelings to bench-marks; and the longer series was the more defective in this respect.

There may be local peculiarities affecting the mean range of this tide on an earth not absolutely rigid, but it is inconceivable that the period should differ from station to station. Comparing the longitudes, dates, and epochs, a period of

$$432\overset{d.}{.}6 \pm 3\overset{d.}{.}2$$

would make the waves identical, a very gratifying result, and one to which some weight might be given; but it suffices to take the simple mean of the periods determined from the independent series, which is much the stronger value, and write

$$\textbf{Period} = \overset{d.}{431} \pm \overset{d.}{4}$$

where the probable error is doubtless a very fair measure of the precision of the determination. If we neglect any possible local influence upon the range, and a here insensible difference due to difference of latitude, we may take the mean and write for both stations the half range as

$$a_1 = \underset{\pm 6}{\overset{ft.}{0.049}} = \underset{\pm 7}{\overset{in.}{0.59}} = \underset{\pm 2}{\overset{mm.}{15}} = \underset{\pm 18}{0''.144}$$

and this, considering the character of the observations, seems a just conclusion from the data. Hence, neglecting an immaterial adjustment of the epochs, we may write for the first term of the latitude-variation tide, as deduced from tidal observations at these two stations, the following values:

SAN FRANCISCO.

$$\left.\begin{matrix} \overset{mm.}{15} \\ \pm 2 \end{matrix}\right\} \cos \left\{ \frac{360^\circ}{431 \pm 4} t - \left(\begin{matrix} 123^\circ \\ \pm 12 \end{matrix} \right) \right\},$$

t reckoned in days from September 21, 1872.

Minimum, 1872, July 15 ± 15.
Maximum, 1873, February 15 ± 15.

PULPIT HARBOR.

$$\left.\begin{matrix} \overset{mm.}{15} \\ \pm 2 \end{matrix}\right\} \cos \left\{ \frac{360^\circ}{431 \pm 4} t - \left(\begin{matrix} 41^\circ \\ \pm 8 \end{matrix} \right) \right\},$$

t reckoned in days from February 3, 1879.

Minimum, 1878, August 22 ± 10.
Maximum, 1879, March 25 ± 10.

Comparison with Other Results.

In the United States Coast and Geodetic Survey Bulletin No. 32, page 112, the corresponding term in the latitude-variation, as derived from elaborate zenith telescope observations made at San Francisco for the purpose of determining that variation, is

$$0''.172 \sin \left(\frac{360^\circ}{431} t + 3^\circ.7 \right),$$

t reckoned from January 0, 1891. Comparing this with the result from the tidal observations at San Francisco, we obtain a period of

$$\overset{d.}{427.8}.$$

The interval between dates is over 18 years; hence this value of the period is entitled to great weight. The divergence of the axes is seen to be identical with that derived from the tidal observations at the same station.

In No. 3261 of the Astronomische Nachrichten, Dr. Bakhuyzen gives the results of his search for the latitude-variation tide, using the tidal observations for the 38 years 1855 to 1892, inclusive, from a mareograph at Helder, about 40 English miles north-northwest of Amsterdam. The series covers practically the same years as that at San Francisco, and hence the results should be directly comparable without sensible error arising either from variability of the period

of the tide or from excess or deficiency in its computed value. Dr. Bakhuyzen finds for the half range

$$a_1 = \overset{mm.}{8.2};$$

and he reduces the tide to Berlin and gives the Julian date of maximum latitude as derived therefrom, and also as derived from astronomical observations. Turning the San Francisco tide forward to Berlin we have:

Julian Date of Maximum Latitude of Berlin.

	Julian date.
Bakhuyzen, from astronomical observations....	2405141
" from Helder tides..................	201
Christie, from San Francisco tides	153 $\pm$ 16,

a reasonably satisfactory accord.

ALASKA AS IT WAS AND IS: 1865–1895.

BY

WILLIAM HEALEY DALL.

[The annual presidential address, delivered before the Philosophical Society of Washington, December 6, 1895.]

In 1864 the apparent hopelessness of the attempts to establish a workable transatlantic telegraph cable led those interested in telegraphic communication with Europe to consider other means of attaining that end. It was thought that a short cable across Bering strait might be made to work, and no doubt was entertained of the possibility of maintaining the enormously extended land lines which should connect the ends of this cable with the systems already in operation in Europe and the United States. A company was formed for this purpose, and an expedition to undertake the explorations necessary to determine the route was organized. The coöperation of the Russian and American governments was secured and the necessary funds subscribed. Searching for properly qualified explorers, the promoters of the enterprise consulted the Smithsonian Institution and were brought into communication with Robert Kennicott, of Chicago, a young and enthusiastic naturalist, who had already made some remarkable journeys in the Hudson Bay territories in the interest of science. His explorations had taken him to the most remote of the Hudson Bay posts—Fort Yukon, on the river of the same name—regardless of every kind of hardship, privation, and isolation. His ardor was so contagious that before returning to civilization he had communicated it to almost every one of

the hard-headed fur traders in that remote and inhospitable region, and for years afterward bird skins, eggs, ethnological specimens, and collections in every branch of natural history poured from the frozen north into the Smithsonian Museum by hundreds and thousands.

When Kennicott, after traveling for months on snowshoes, sledges, or bateaux, stood at last on the steep bluff at Fort Yukon, he saw the yellow flood of the great river surging by the most remote outpost of civilization and disappearing to the westward in a vast and unknown region. An uninhabited gap of hundreds of miles lay between him and the nearest known native settlement to the west. Far in the north the midnight sun lighted up the snowy peaks of the Romanzoff mountains, whose further slope it was believed gave on the Polar sea. No one knew where the Yukon met the ocean. On most maps of that day a large river called the Colvile, found by Simpson on the Arctic coast as he journeyed toward Point Barrow, was indicated as the outlet of the Yukon watershed. South of the Romanzoff mountains for an unknown distance vast tundras, scantily wooded with larch and spruce, the breeding grounds of multitudes of water fowl, intersected by many streams, but level as a prairie, extended to the west.

The native population of this region, as far as known, had always been scanty, and an epidemic of scarlet fever, introduced some years before through contact with other tribes trading to the coast, had swept them absolutely out of existence. Not an individual was left, and the nomadic natives who reached Fort Yukon from the east and southeast hesitated to approach the hunting grounds, where the mysterious pestilence might linger still.

Obliged to terminate his explorations here, Kennicott returned, after months of weary travel, to the United States, but cherished the hope of some day penetrating the *terra incognita* on whose borders he had been obliged to pause and turn away. The dream of his life was thereafter the exploration of Russian America, the discovery of its fauna,

and the determination of its relations to the fauna of Siberia and Japan. The group of young zoölogists which gathered about him at the Chicago Academy of Sciences, an institution of which Kennicott was practically the creator, was frequently roused to enthusiasm by impromptu lectures on the problems to be solved, the specimens to be collected, and the adventures to be anticipated in that virgin territory.

The need of the telegraph company for one familiar with life and conditions in the north brought him the long sought opportunity, and he undertook to lead the exploration, provided he was permitted to utilize it for science to the fullest extent commensurate with the attainment of the objects of the expedition. He stipulated that he should be permitted to select a party of six persons who should be qualified to make scientific observations and collections in the intervals of other work, but who should hold themselves ready to do any work required by the promoters of the enterprise, even to digging post-holes for the line if called upon.

His terms were accepted, and the scientific corps of the expedition organized and started for San Francisco. Here two of the members were detailed to join the party engaged in exploring the route through British Columbia; the others, of whom the speaker was one, accompanied Kennicott to the north.

In July, 1865, the expedition entered the bay of Sitka and our acquaintance with Russian America began.

Sitka was then a stockaded town of about 2000 inhabitants, with a village of more than 1500 Indians outside the walls. The settlement contained a Greek church, a Lutheran chapel, shipyards, warehouses, barracks, a clubhouse for the officers, a sawmill, a foundry where brass, copper, and iron castings of moderate size were made, beside numerous dwellings. All the buildings were log structures, their outer walls washed with yellow ochre, the roofs chiefly of metal painted red. High above the rest, on an elevated rock, rose a large building, in which the governor of the Russian colonies had his residence. This, known to visitors

as the " castle," was built of squared logs, with two stories and a cupola and was defended by a battery. The warm colors of the buildings, above which rose the pale green spire and bulbous domes of the Greek church, seen against steep, snow-tipped mountains densely clothed with sombre forests of spruce, produced a picturesque effect unique among American settlements.

Outside the walls, along the beach, was a long row of large Indian houses, low and wide, without windows, built of immense planks painfully hewn out of single logs with stone adzes, whose marks could still be distinctly seen. They were entered by small, low doors, rounded above, so that he who came in must bend to an attitude ill suited to defense. The front of each house was painted with totemic emblems in red ochre. Their dimensions were sometimes as much as 40 by 60 feet, and the area within formed one large room, with the rafters visible overhead, the middle portion floored only with bare earth, on which the fire was built, the smoke escaping through a large square hole in the roof. On either side were raised platforms with small partitioned retreats like state-rooms, each sheltering a single family. As many as one hundred people sometimes dwelt in one of these houses. The only ornaments were totemic carvings, generally against the wall opposite the entrance; overhead hung nets, lines, and other personal property drying in the smoke along with strips of meat or fish and fir branches covered with the spawn of herring.

On the bank, which rose behind the houses, densely covered with herbage of a vivid green, were seen curious box-like tombs, often painted in gay colors or ornamented with totemic carvings or wooden effigies. These tombs sheltered the ashes of their cremated dead. On the beach in front of the houses lay numerous canoes whose graceful shape and admirable workmanship extorted praises from the earliest as well as the later explorers of the coast. When not in use these were always sheltered from the sun by branches of spruce and hemlock or tarpaulins of refuse skins. Among

the canoes innumerable wolfish dogs snarled, fought, or played the scavenger.

The natives still retained to some extent their original style of dress, modified now and then by a Russian kerchief or a woolen shirt. As a rule, they were barefooted, stolid, sturdy, uncompromising savages, who looked upon the white man with a defiance but slightly tempered by fear and a desire to trade. The mission church of that day was built into the stockade, with doors entering it both from the Indian and the Russian town. When services were held the outer door was opened, the town door closed and stoutly barred. Once these fierce clansmen had endeavored to rush into and take the settlement when the door leading inward had been left unfastened. From the time when the first white men to touch these shores, Chirikoff's boat's crew in 1741, were without provocation massacred, these natives had not failed to maintain their reputation for courage, greed, treachery, and intelligence.

These conditions outside the settlement necessitated a military discipline within it. Sentries regularly paced the walks by day and night, the sullen Indians were systematically watched, and the little batteries kept in readiness for use.

The needs of the business of the company made Sitka a lively manufacturing town, in spite of the multitudinous Russian holidays. Society there was like a bit of old Russia, with the manners, vices, and sturdy qualities of sailor, peasant, and courtier fully exemplified within its narrow limits. A fishery at Deep lake, a few miles away, furnished fresh salmon in abundance, which was freely distributed to all comers twice or thrice a week during the season. The company furnished each employé with certain stated rations of flour, sugar, tea, etc., at fixed prices; the harbor, within a few yards of the stockade, contained abundance of seafish, and the Indians' price for a deer, skinned and dressed, was a silver dollar or a glass of vodka. The primeval forest came close to the town; the demand for firewood and timber had made little impression upon it. White settlements in the

Alexander archipelago were confined to a few small fortified trading posts. Fort Wrangell and Fort Tongass alone could be regarded as approximately permanent. The parties sent out to trade or hunt worked from a temporary camp or an armed vessel as a base, and, owing to the ill-feeling which existed between the natives and Russians, smuggling and illicit trading were rife. Missionary effort did not exist outside of Sitka, and even there amounted to little more than the bribery of some greedy savage to perform for a consideration some rites which he did not understand.

The law of Russia which prevented a permanent severance of a subject from his native soil (except for crime) operated to encourage temporary unions of the company's servants with native women. Marriages were not allowed between full-blooded Russians and natives, as at the expiration of his term of service the Russian must return to his own parish in Russia, and the native could not be carried away from the place of her nativity. After the transfer of Alaska to the United States many of these Russians elected to remain in the country and were married to the mothers of their children; but at the time of our first visit the most surprising social fact to us was the perfect equality which appeared to subsist between these irregular partners and the married women who had come from Russia. So far as we could perceive, both classes behaved with equal propriety and were treated with equal respect by the community, and the only restriction which the authorities insisted upon was that no Russian should take to himself a partner who had not been duly baptized. The issue of these unions, being of Alaskan birth, were free to marry in the country, and with their descendants constituted the class to which the Russians gave the name of "Creoles." Some of them rose to eminence in the service, and one at least became governor of the colonies.

At the time of our visit the business of the colony was exclusively the development of the fur trade. Agriculture was confined to a trifling amount of gardening very imperfectly performed. The fisheries were utilized only to supply food

for the people in the company's employ, or to insure subsistence for the natives whose time was devoted to hunting the sea otter or preparing skins for the authorities. The fur trade of southeastern Alaska was not very productive. The natives were disposed to trade with the Hudson Bay Company or illicit traders rather than with the Russians, partly because they obtained better prices for their skins and partly because the Russians refused to trade intoxicating liquors, while the outsiders were not troubled with any scruples in such matters. The furs were divided by the Russians into two classes—the precious furs, such as the fox, sea otter, and sable, which were strictly reserved for the company, a certain proportion being imperial perquisites of the Russian court, and the cheaper sorts, which might be used by the company's employés for winter clothing, and were sold at a fixed price to them for this purpose. This included the muskrat, mink, Parry's marmot or ivrashka, the fur seal, and some others. Dry skins of the fur seal were sold at the company's warehouse for 12½ cents apiece, the modern plucking and dyeing of the fur, invented by an American, Raymond, of Albany, not having reached a perfection sufficient to attract the fashionable world.

The European trading goods and supplies were mainly brought by ship from Hamburg, the same vessel taking the annual load of skins to China, where an exchange was made for tea and silk, which were carried back to Europe. Flour was imported latterly from California and some goods were brought from Aian and other ports on the Okhotsk sea in the early days of the business, but in 1865 this trade had come to a standstill or nearly so. In mineral resources almost nothing was done ; a little coal was taken out at Cook's inlet for local uses, and the exportation of ice from Kadiak to California was carried on under a lease by an American company. The presence of gold, iron, and graphite was known to the authorities, but prospecting was not encouraged, as it was supposed the development of mineral resources might react unfavorably on the fur trade.

The first codfisherman visited the Shumagin islands in 1865. The whale fishery was wholly in the hands of Americans and other foreigners, uncontrolled by the Russians, and the timber was used only for local purposes.

The main business of the company was done at its continental trading posts in the northern part of the territory and in the Aleutian chain; its authority in the territory was as absolute as the presence of the uncivilized tribes would admit. Under the guns of the trading posts the company was master; out of their range every man was a law unto himself.

After transacting its business at Sitka the expedition touched at the island of Unga to examine a coal mine, at Unalashka, the Pribiloff islands, and at Saint Michael's, Norton sound, where Kennicott and the explorers for the Yukon were landed. The speaker was put in charge of the scientific work of the expedition and remained with the fleet, visiting Bering strait, where landing places for the cable were searched for; and Petropavlovsk, the capital of Kamchatka, where the Siberian parties were provided for; and then the vessels returned to San Francisco.

The following year, on returning to Saint Michael's, we were met by the news of Kennicott's death from heart disease, brought on by over-exertion and anxiety. The Yukon exploration was still incomplete, though information received made it certain that the Kwikhpak of the Russians and the Yukon and Pelly of the English were one and the same river. It remained to emphasize this information by a continuous exploration which should cover the unmapped portion of this mighty stream. The scientific work in zoölogy projected by Kennicott had been left by his premature death unrealized. The speaker determined to carry out these plans and was authorized to remain in the country for that purpose.

As soon as sufficient snow had fallen to render sledging practicable a portage from Norton sound to the Yukon river was traversed, a small boat transported on a sledge for use

during the following summer, and the Yukon ascended on the ice to the trading post at Nulato, a distance of some three hundred miles. Here the party of five wintered and in March divided into two parts—one, under Frank Ketchum, taking sledges with the intention of traversing the unknown region on the ice and after reaching Fort Yukon to ascend further in canoes; the other to await the break-up of the ice in May and follow in the skin canoe, so as to rescue the first party should they have failed to carry out their plans. Both projects were successfully carried out and the two parties reunited at Fort Yukon on the 29th of June, 1867. They returned by the whole length of the river and reached Saint Michael's on the 25th of July. Here astonishing news awaited us: The Atlantic cable was a triumphant success, the United States were in negotiation for the purchase of Russian America, our costly enterprise was abandoned, and all hands were to take ship for California.

The collections and observations had been but half completed. The natural history of the Upper Yukon and the borders of Norton sound had been pretty well examined, but the vast delta of the Yukon, with its wonderful fauna of fishes and water birds, its almost unknown native tribes and geographic features, remained practically untouched. I immediately determined to remain and devote the following year to the unfinished work. An arrangement with the Russians was made and this plan carried out. In the autumn of 1868 I left Norton sound for California on a trading vessel and returned to civilization.

At the time our explorations of the Yukon began this immense region was occupied by two or three thousand Indians, many of whom had never seen a white man. The Russian establishments on the Yukon were only three in number, hundreds of miles apart, and chiefly manned by Creole servants of the company, not over a dozen at each post. An inefficient priest, with a few alleged converts, conducted as a mission of the Greek church the only religious establishment in the whole Yukon valley. The industries of

the region comprised trapping, hunting, and fishing; the first for revenue, the others for subsistence. The means of navigation were birch-bark canoes and small skin-boats. Once a year the clumsy barkass of the Russians, loaded with tea, flour, and trading goods, was laboriously forced upstream to the Nulato post, returning with a load of furs. The tribes of Eskimo extraction occupied the lower river banks from the sea to the Shageluk slough, above which they were replaced by Indians of the Tinneh stock. These were to be found in scattered villages at various points on the river or its tributaries, where the abundance of fish offered means of subsistence. The extreme limit of population was to be found at the junction with the Yukon of the large river Tananá, where the island of Nūklūkayét was recognized as neutral ground, where delegations from all the tribes met in the spring for their annual market of furs. Here our party had the interesting experience of meeting the delegation of Tananá Indians in full native costume of pointed shirts and trousers of dressed deerskin adorned with black and white beads, the nasal septum pierced to carry an ornament of dentalium shell, their long hair formed into a bundle of locks, stiff with tallow, wound with beads, dusted with powdered hematite and the chopped down of swans. The ranks of frail birch canoes were accurately aligned, and their paddles rose and fell with military precision. When they rounded the point of the island and approached the beach, where stood the first white men they had ever seen, they were met by a complimentary salvo from the guns of the Indians already on shore, and responded by wild yells and graceful waving of their paddles.

The waters of the Tananá had never known an explorer and its geography was wholly unknown. Never again will it be possible for an ethnologist to see upon the Yukon such a body of absolutely primitive Indians untarnished by the least breath of civilization.

Above Nuklukayét the Yukon enters a cañon, known as the Lower Ramparts, above which the depopulated area already

alluded to extends to the site of Fort Yukon, near the British boundary on the Arctic circle.

The noble stream I have described extends, including windings, about 1,600 miles from Fort Yukon to the sea. The valley is sometimes wide and low, sometimes narrow and contracted by low, wooded mountains. Everywhere until the delta is approached the banks are wooded. There are many tributaries, none of which were then explored, and on either side of the main artery the land stretched unexplored for hundreds of miles. Not another person speaking any European tongue except the Russian was resident in all this territory during the second year of my sojourn. Outside of the three trading posts, not a native had ever bought a pound of flour or an ounce of tea. The use of woolen clothing had hardly begun, and soap was a rare and costly luxury. I made the first candles ever molded on the Yukon, and but for the lack of hardwood ashes to furnish alkali would have tried my hand at soap. People lived on game and fish. The caribou was plentiful in the absence of rifles; the moose was not yet exterminated; the warm days of spring brought incalculable multitudes of ducks and geese, to say nothing of other water fowl; the Arctic rabbit and the ptarmigan were a constant resource, and the rivers and lakes in many places teemed with fish. Clothing was made of deerskin and sewed with sinew; the ornaments were fringes from the gray wolf or wolverine. Undergarments were occasionally made of cotton bought from the traders, but more usually from the skins of fawns. At one village during the season for taking them I saw 4300 fawn skins hanging up to dry. Such reckless destruction has since borne its natural fruit. It was only at certain localities even then that deer were plentiful. The main staple of subsistence was fish. During the summer the river was studded with traps for salmon; in winter the traps were set in the ice, and under favorable conditions furnished a steady supply of white-fish, burbot, pike, grayling, and the great red sucker. The salmon were cleaned, split into three parts connected at the tail,

and dried in the open air by millions; they furnished food for man and dog, and when well cured were not unpalatable. Vegetable food was almost unknown, except in the form of berries. The green flower stalks of *Rumex* and *Archangelica* were occasionally eaten, and the dwellers by the sea sometimes gathered dulse, but for practical purposes the diet was meat and fish.

It was known that gold existed in the sands of the river, but the inexperienced fur traders looked for it in the bars of the main river and not in the side cañons of small streams, where it has since been found in such abundance. The real riches of the Yukon valley then lay in its furs. In a garret at Fort Yukon the post trader showed me with pardonable pride 300 silver fox skins of the first quality. Beautiful in themselves and for what they represented—gold, praises, and promotion in the service—one might almost forget that some of the company's servants at this post had not tasted bread or butter, sugar or tea for seven long years.

The region of the delta was and is still remarkable as being the breeding place of myriads of water fowl, some of which are peculiar to the Alaskan region. Nearly one hundred species gather there, and one of them comes all the way from north Australia, by the coasts of China and Japan, to lay its eggs and rear its young in the Yukon delta. It is also remarkable for the abundance of the great king salmon, sometimes reaching a weight of 130 pounds, a fish less plentiful further up and which does not ascend to the headwaters of the river.

All this immense territory has since been penetrated by traders and prospectors. Stern-wheel steamers have defied the current, and ply regularly on the river during the season of open water. Mission schools are numerous and reindeer scarce. The fur trade wanes, while many thousands of dollars in gold dust have been laboriously extracted from the gravels. The natives buy tea and flour and dress in woolen clothing. With the miners whisky has reached the wilderness, and the sound of the American language is

heard in the land. Tame reindeer have been imported from Siberia with a view to their domestication by the Eskimo of the Arctic coast, who are on the verge of starvation at frequent intervals, owing to the destruction of their food supply by the whalers and walrus-hunters and the introduction of Winchester rifles for killing the wild deer. With the alternative of starvation as a stimulus, the chances of success ought to be good.

In carrying out the plans which Kennicott had meditated, but which death had stayed, I had succeeded in gathering rather abundant material for my friends, the ornithologists, botanists, ethnologists, and so on, but to do it I had to put aside the work in the department in which I personally was most interested. The shores of Norton sound and the tundra of the Yukon valley offered little in the way of mollusks or other invertebrates. The desire to extend our knowledge of the geographical distribution of the sea fauna led me to propose a further exploration of the coasts of the territory, especially of the Aleutian chain, under the auspices of the United States Coast Survey. A geographical reconnaissance was undertaken and carried on during five years, investigating magnetism and hydrology, making charts, tidal observations, meteorological and hypsometric notes. In all this I was ably seconded by my companions, Mark W. Harrington and Marcus Baker, who need no introduction to this audience. At the same time and without interfering with the regular work the dredge was kept constantly busy, and on my return from field-work the material for the studies I had so long looked forward to was actually gathered.

The region which includes the Aleutian chain and other islands west of Kadiak presents a striking contrast to the densely wooded mountains and shining glaciers of the Sitkan region to the east and the rolling tundra cut by myriad rivers in the north. Approached by sea, the Aleutian islands seem gloomy and inhospitable. Omnipresent fog wreaths hang about steep cliffs of dark volcanic rock. An angry

surf vibrates to and fro amid outstanding pinnacles, where innumerable sea birds wheel and cry. The angular hills and long slopes of talus are not softened by any arborescent veil. The infrequent villages nestle behind sheltering bluffs, and are rarely visible from without the harbors. In winter all the heights are wrapped in snow, and storms of terrific violence drive commerce from the sea about them.

Once pass within the harbors during summer and the repellent features of the landscape seem to vanish. The mountain sides are clothed with soft yet vivid green and brilliant with many flowers. The perfume of the spring blossoms is often heavy on the air. The lowlands are shoulder high with herbage, and the total absence of trees gives to the landscape an individuality all its own. No more fascinating prospect do I know than a view of the harbor of Unalashka from a hilltop on a sunny day, with the curiously irregular, verdant islands set in a sea of celestial blue, the shorelines marked by creamy surf, the ravines by brooks and waterfalls, the occasional depressions by small lakes shining in the sun.

The sea abounds with fish; the offshore rocks are the resort of sea-lions and formerly of sea-otters; the streams afford the trout-fisher abundant sport, and about their mouths the red salmon leap and play. In October the hillsides offer store of berries, and in all this land there is not a poisonous reptile or dangerous wild animal of any sort.

The inhabitants of these islands are an interesting and peculiar race. Their characteristics have been well described by Veniaminoff, who knew and loved them. By the testimony of their language, physique, and culture they are shown to be a branch of the Eskimo stock, driven from the continent, as the shell-heaps reveal, at a very ancient date and isolated since from contact with any other native race, specialized and developed by their peculiar environment to a remarkable degree. Conquered by the Russian hunters of the eighteenth century, practically enslaved for a century, their ancient religion frankly abandoned for the rites of the

Greek church, an apathetic reticence replaced the rollicking good nature characteristic of the Eskimo people. In 1865 they were supported by the company; the men shipped off in hunting parties in search of the sea-otter were separated from their families sometimes for many months and rewarded according to their success; but, while the company provided food for all who needed it, the time of the Aleut was not his own. I have already mentioned that the fur-seal at that time had very little commercial value. The fishery on the Pribiloff islands was conducted by Aleuts under supervision, and the skins were mostly shipped to China or Europe. It has been noted as surprising that the value of the fur-seal fishery is so little referred to in the arguments urging the acquisition of the territory in 1867. This was not an oversight; the seal fisheries at that time were not especially lucrative, and the millions which the industry has since produced could not have been predicted in 1867.

At the time of my first visit and until very recently the sole productive industry of the Aleut people consisted in the sea-otter hunting and the fur-seal fishery. Much of their subsistence was and is obtained from the natural products of the region—fish, wild fowl, and the flesh of marine mammals. The custom of preparing clothing from the skins of birds and animals has long been abandoned. The Aleut and his family now dress in clothing of wool or cotton, burn kerosene in an American lamp, and cook their food on an iron stove. The barábora or native hut, built of sod and stones, has been generally replaced by a frame cottage, and the means for supplying these artificial wants has been obtained from the income derived from the seal and sea-otter. Now that these animals are approaching extinction, at least from a commercial standpoint, the question of how to provide even the modest income needed for these people is a serious one. While it is not yet settled that the half-starved Eskimo of the northern coast will adopt the new mode of life necessitated by the care and maintenance of large herds of tame reindeer, and the success of that experiment is still

questionable, there is no doubt in my mind that the introduction of the deer into the Aleutian chain is not only perfectly practicable, but that it offers the only solution of the problem of providing for the Aleuts which seems to possess the elements necessary for success. There are no predacious animals to molest the deer, like the wolves of the mainland; there is an abundant supply of forage, and the climate and conditions are those that the animal is known to thrive in. A herd introduced a few years ago into Bering island, on the Russian coast, and simply let alone and protected from dogs, has increased very much in number and will soon afford skins and tallow for export. There is no obvious reason why on most of the Aleutian islands equally good results should not be obtained. Some few deer were introduced upon the island of Amaknak, in the bay of Unalashka, a few years since, but they were the property of whites, not natives, were not protected from the numerous dogs of an adjacent settlement, and have not thriven.

When the time comes, and it seems not far away, when the natives realize that they must depend on the deer to replace the vanishing fur animals as a source of income, and when they can acquire property in deer, I believe the result will be all that could be wished.

In closing this summary of early conditions in the Territory and of the events which enabled them to be observed, it may not be out of place to summarize also the results of the scientific work of those years. Of course, only the more important points can be alluded to. As the Western Union Telegraph Expedition ended by a withdrawal from the country, and was the occasion of a large expenditure of money with no return to its promoters, no general report was ever officially prepared, and the work of the scientific corps was made known piecemeal in various technical journals. The published results were associated in the minds of students with the individual authors rather than with the expedition as a whole. The subsequent work under the auspices of the Coast Survey, which in fact grew out of the

work done or attempted in the earlier exploration, has been, so far as it was geographical, regarded very naturally as incidental to the usual work of that bureau, and so far as it has been of other sorts has not been connected in the public mind with any organization in particular. The fact that the Revenue Marine, the Army and Navy, the Signal Service, and several unofficial organizations or individuals have carried out praiseworthy explorations with most excellent results has led to the further obscuration of the earlier work as a connected whole. I believe no one of those engaged in it has yet attempted to enumerate the results, either general or scientific, directly or indirectly consequent upon the expedition. The present summary may therefore serve a useful purpose.

The most important result which indirectly came about from the explorations by our parties was the acquisition of Alaska by the United States. While the transfer might have been proposed and the question discussed if there never had been any Telegraph expedition, yet I believe, in view of the opposition which existed in Congress and the cheap ridicule of part of the daily press, that if it had not been for the interest excited by the expedition and the information which its members were able to furnish to the friends of the purchase the proposition would have failed to win approval.

But, leaving such questions apart and considering merely the scientific results, the expedition made weighty additions to geographical knowledge. To it we owe the first mapping of the Yukon from actual exploration, adding to the list of American rivers one of the largest known. Old maps of North America made the Rocky mountains extend in nearly a straight line northward to the Polar sea. Our explorations showed that the mountains curved to the westward, leaving a gap to the northward through which the Canadian fauna reached to the shores of the Pacific and Bering sea. The general faunal distribution of life at this end of the continent in its broader sense was settled then and there. A general knowledge of the country, till then practically un-

known except to a few fur traders, was obtained and made public. To the Coast Survey work of 1871–'74 we owe some forty charts, a large proportion of which are of harbors or passages never previously surveyed. In preparing a Coast Pilot of southeastern Alaska, while that part of it useful to navigators was in the nature of things rapidly superseded, yet the work, being conscientious and thorough in the matter of names, practically settled the geographic nomenclature of that region for all time. The myth of a branch of the Kuro Siwo or Japanese warm current running north through Bering sea and strait and producing open water in the Polar sea still lingers in some dark corners of geographic literature; but our researches, covering actual observation, the whole literature, and scores of old manuscript logbooks, conclusively show that there is no such current as that referred to, and that the currents which do exist have no connection whatever with the Japanese stream. Meteorological observations were kept up in all those years, and afterward a complete synopsis of all the recorded meteorological data for that region was prepared and issued by the Coast Survey with abundant illustrations. One of the results of the magnetic observations made by our party, in the endeavor to correct the discrepancies between the variation of the compass needle as shown on the charts of Bering sea and strait and those observed by present navigators, was the discovery that the needle had reached its easternmost elongation and had for some time been receding in the amount of its variation. In gathering confirmatory data during 1874 and 1880 more than forty stations in all parts of the territory were occupied. As in the case of the meteorology, the literature and all practicable sources were ransacked for magnetic records,* and these, with our own observations, were utilized in the excellent discussions of Alaskan magnetism by Dr. C. A. Schott.

In geology we were tutored before sailing in 1865 by Professor Agassiz and carried with us a written schedule of ob-

* This work was almost entirely done by Mr. Marcus Baker.

servations to be made on the glaciers. Our explorations showed that north of the Alaskan mountains, as in some parts of Siberia, there are no glaciers, and there has been no glaciation in the ordinary sense, but that in its stead we have the singular phenomenon of the Ground-ice formation, a state of affairs in which ice plays the part of a more or less regularly interstratified rock, above which are the clays containing remains of the mammoth and other animals, showing that they became extinct not because of the refrigeration of the region, but coincidently with the coming of a warmer climate.

In anthropology, in addition to large collections obtained from the living tribes, vocabularies, etc., the names and boundaries of all the tribes were obtained for the first time, the Eskimo were shown to exist on the Asiatic coast as immigrants driven by war from America, and a very ancient confusion of these people with the Asiatic Chukchi was definitely cleared up. The data obtained in regard to the various branches of the Eskimo stock brought welcome confirmation to the theory of Rink on the origin of this people—a theory which would probably have been by this time more widely known if it had been more sensational and less scientific.

The patient examination of many village sites, shell-heaps, and middens throughout the Aleutian chain resulted in the discovery that the successive strata, judged by the implements found in them, showed a gradual progress in culture from that of the lowest, a crude Eskimo type, to that of the uppermost stratum, which contained the evidences of Aleut culture of the type immediately before their subjugation by the Russians. This was, I believe, at that time the first instance in which the paleontologic method, if I may call it so, had been applied to the study of American shell-heaps.

In biology, the first object of the work planned by Kennicott had been the determination of what constituted the fauna and flora, and from that knowledge the determination of the relations between the Asiatic and American assemblies. This was accomplished in essentials, though it need

not be said that the details will still supply an opportunity for study for many a year to come. The enumeration of the greater part of the population of mammals, birds, and fishes has been accomplished and the plants have been fairly well collected, so that we know that the fauna and flora, deduction being made of circumboreal species, is essentially American and not tinctured to any marked extent with Asiatic ingredients. Among the lower animals the brachiopods, hydroid zoöphytes and corallines; part of the sponges; the limpets, chitons, and nudibranchs among the mollusks; have been monographically studied. The crustacea, insects, and a large part of the mollusks yet remain to be worked up in a similar manner.

To close the record of achievement, I may mention the bibliography of Alaskan literature prepared by Mr. Baker and myself, which, up to May, 1879, when it went to press, comprised 3,832 titles in eleven languages. Since it was published by the Coast Survey nearly as many more have been accumulated, and the list probably will continue to increase from year to year.

Since my field-work closed, in 1880, Alaskans have not been idle. The prospector has invaded the recesses of the land, and surveys, explorations, and mountaineering have been almost constantly carried on. The tourist has discovered the country and written books which, although they have the resemblance of one pea to another, have nevertheless carried tidings of Alaska to most corners of the Union. Alaska in one sense is no longer unknown, and she is even beginning to be somewhat understood and appreciated. The missionary has been up and down in the land, and has done much good in many ways, not without occasional mistakes.

It was, therefore, with curiosity as well as interest that I returned to the territory last May, after an absence of fifteen years. In looking back on the summer's experiences, a comparison between the Alaska of 1865 and that of 1895 naturally suggests itself. I was rash enough twenty-five years ago to indulge in prophecy as to the future of the territory.

I did not count on the inertia of Congress or the stupidity of officials, as I might now. Nevertheless progress has been made, and a summary of present conditions, perhaps even a peep into the future, is not inappropriate at this time.

Since 1865 the fur-seal fishery has risen, produced its millions, and declined to a point where its close in a commercial sense may almost be predicted. The first fisherman sought the cod in that year, and a modest fleet has kept the business going ever since, with more or less fluctuation in the catch. The salmon canner was then unknown, but has since invaded nearly every important fishing site. The placer miner has developed and exhausted the gold of the Stikine region, and pushed on to the headwaters of the Yukon and its affluents. The clink of the drill and the monotonous beat of the stamp-mill are familiar sounds on the quartz ledges, which in 1865 lay peacefully under their blankets of moss. The whaling fleet has laid its bones on the sandy bars of the Arctic coast, while the innovating steam whaler has pushed its way past Point Barrow into the very fastness of the ice at Herschel island, to find, in its turn, its occupation gradually passing away. The imperial sea-otter is on the way to becoming a memory, and the Aleuts, his persecutors, are not unlikely to follow him.

As regards the inhabitants of the territory, a complete change is conspicuous. Some thousands of white fishermen, hunters, miners, and prospectors are now scattered along the coast and rivers, on the whole a hard-working, orderly set, with here and there a rascally whisky smuggler or a stranded gentleman. Apart from a few mining camps, the parasites who live by the vices of others are few. A country where he who would live must work is not attractive to them. Cut off from direct contact with the rest of the United States, Alaska is really a colony and not a frontier territory in the sense usually understood. As such, its needs should have been the subject of study and appropriate legislation, the neglect of which by Congress so far is bitterly and justly resented by the entire population. Into political matters I

shall not enter, but must observe that among the numerous ill-paid officials few are well prepared to handle all the difficult questions presented in such a community, and the executive, such as it is, is without the legal authority or the proper facilities for governing or even visiting the greater part of the region it is supposed to control. The state of the law is uncertain, the seat of authority obscure, divided illegitimately between naval officers, the revenue-cutter service, and a powerless governor, who, whatever his wishes and intentions, is not permitted by the law to control anything. If it were not for the orderly character and good sense of the white population, the territory might easily become a pandemonium. This condition of things is disgraceful, and reform is urgently needed.

The change in the native population of southeastern Alaska is very marked. In a general way a similar change has taken place all over the territory. The primitive condition of the natives has almost wholly disappeared. The turf-covered hut has given way to frame shanties; log houses are rarely built; the native dress has disappeared, replaced by cheap ready-made clothing; native manufactures, utensils, weapons, curios, all are gone, or made only in coarse facsimile for sale to tourists; the native buys flour and tea, cooks his salmon in a frying-pan, and catches his cod or halibut with a Birmingham hook and a Gloucester line. In the whole of southern Alaska, thanks to the schools, the children and many young people speak fairly good English. If the present influences continue, another generation will see the use of English universal and the native languages chiefly obsolete. The day of the ethnological collector is past. Southeastern Alaska is swept clean of relics; hardly a shaman's grave remains inviolate.

In other parts of the territory the same is more or less true. The native population is focusing about the commercial centers. The people gather where work and trade afford opportunities, and I have seen more than one pretentious church standing empty among the abandoned houses of a

formerly prosperous village. There is some admixture of blood in marriages between the often attractive "Creole" women and the incoming settlers. These marriages are often very fruitful, but the pure-blooded natives seem to be diminishing. The Aleuts, whose census is accurately made annually by the Greek church, are distinctly losing ground, and will doubtless pass away in a few generations. The same is probably true of the Tlinkit people. As we approach the Arctic region, changes of all sorts are less marked and civilization has had less effect. Here the subsistence of the natives presents serious and increasing difficulties. Their natural food supply has been practically destroyed by the whites and by repeating firearms, of which the natives have many. The whales are almost extinct, and the whaling fleet itself is nearly so. The walrus preceded the whale, and the hair seal has never been sufficiently abundant in this region for a sole resource. The chief salmon streams are or soon will be monopolized by the whites near the sea, and the natives of the upper Yukon will go hungry. The present law allows unrestricted fishing to the natives and a close time of one day a week for the whites. The latter hire the natives to fish during the prohibited day, and so the salmon have no close time. Where a salmon stream is monopolized by one firm, they do not usually cut their own throats by taking all the salmon, but where there are several competing firms there is little respite for the fish.

The cod fishery was for some years carried on by two competing firms, who have now composed their differences. They had salting stations on shore, and bought fish at so much a thousand from fishermen, who used small sailing vessels or dories and fished near shore. Now it is found cheaper and, for other reasons, preferable to return to the older system of fishing in the open sea from a sea-going vessel, as on the banks at the east. The preparation of the Alaska fish has often been hasty, careless, and inferior to that done in the east; so Alaska codfish, originally of equal

quality, are less esteemed commercially than the eastern cod. For some reason I do not understand the Pacific ocean at best offers but a small market for fish under present conditions, and so I look to see the codfishing industry develop slowly and perhaps be the last as it is, in my opinion, the most substantial and important of the resources of the territory. At present the salmon are commercially more important, but unless more effectively supervised and regulated they will meet with the same fate as the fisheries of California and the Columbia river. There should be a resident inspector at every important fishery, and as the business is carried on for at most two or three months in the year, a vigilant inspection by a cutter or fisheries vessel told off for this especial work would counteract any tendency to bribe the resident inspector. I have seen 3,500,000 pounds of canned salmon taken in one season from one small stream, representing at least 5,000,000 pounds of eatable fish, and it seems that an annual supply of the best fish food like that is worth preserving; but if the work is to be put into the hands of the lowest class of political appointees instead of intelligent experts, making the offices will not save the fish.

In the matter of furs we may regard the fur-seal fishery as doomed. It is probable that few of the pelagic sealers will pay expenses after this season, and two or three years are likely to see the end of the business. It is costing us much more than the catch is worth now, and the most sensible way of ending the matter is generally felt to be the destruction at one fell swoop of all the seals remaining on the islands and the abandonment of the business.

The continental furs, owing to competition between traders, are now selling for nearly their full market value, and little profit can be expected from them. They are also growing more and more scarce, as the high prices stimulate trapping. The natural and satisfactory offset to this would be the establishment of preserves, such as the "fox farms," of which mention has been frequently made in the daily press. Many of

these have been started, and the multitudinous islands offer opportunities for many more; but the business is hazardous, since there is no protection against poachers, and a very ill-judged attempt has been made by the Treasury, I am informed, to impose, in addition to the annual sum for which the island is leased, a "tax" of $5 on each fox killed over twenty from each "farm." It is doubtful if the Treasury is entitled to tax anybody without the explicit authority of Congress, and a tax of 50 per cent. on the gross value of the product not only is oppressive and exorbitant, but will put a stop to a business which should be encouraged.

The timber of Alaska, though by no means insignificant, is not likely to be much sought for, except for local purposes, for many years. I may point out, however, that there are millions of acres here densely covered with the spruce best suited for wood pulp, and plenty of water power for pulp-mills, so that this resource is not without a future.

A forthcoming report of the United States Geological Survey will treat of the existing and prospective mining industries.

To sum up, it may be said that the whaling and sealing industries of Alaska are practically exhausted, the fur trade is in its decadence, the salmon canning in the full tide of prosperity, but conducted in a wasteful and destructive manner which cannot long be continued with impunity. The cod and herring fisheries are imperfectly developed, but have a substantial future with proper treatment. Mineral resources and timber have hardly been touched. No business-like experiment with sheep or cattle on the islands has been tried by competent hands, while the introduction of reindeer, though promising well, is still in the experimental stage. Socially, the territory is in a transition state, the industries of the unexploited wilderness are passing away, while the time of steady, business-like development of the more latent resources has not yet arrived. The magnificent scenery, glaciers, and volcanoes make it certain that Alaska will in the future be to the rest of the United States what Nor-

way is to western Europe—the goal of tourists, hunters, and fishermen. Agriculture will be restricted to gardening and the culture of quick-growing and hardy vegetables for local use. The prosecution of most Alaskan industries being in untrained hands, failures and disappointment will no doubt be frequent, but when the pressure of population enforces more sensible methods the territory will support in reasonable comfort a fair number of hardy and industrious inhabitants.

List of Scientific Publications based on the work of the Scientific Corps of the Western Union Telegraph Expedition to Alaska (1865–'68), *and on the United States Coast Survey explorations* (1871–'80), *under the direction of W. H. Dall, in the same region.*

The following list is intended to comprise the titles, in brief, of the more important publications which have arisen directly from the work of the Scientific Corps of the Western Union Telegraph Expedition, and of the supplemental explorations by parties under my direction, in connection with the work of the United States Coast and Geodetic Survey, in the endeavor to complete the interrupted plans of the earlier expedition. For a more complete Alaskan bibliography, to 1879, reference may be had to the publication on that topic hereunder cited. The present list is brought to date, but publications relating only to Siberia are not included; it does comprise, in addition to articles printed by members of the expedition, others by specialists in various departments based on collections brought back for study. Considerations of space forbid an attempt to make this list complete, but, such as it is, it is hoped that it may give a better idea of the additions to knowledge which resulted from the labors of Kennicott and his associates and serve to illustrate a not uninteresting chapter in the exploration of Northwest America. It should, however, be clearly understood that a considerable amount of exploration, growing out of subsequent events not

connected with the Telegraph expedition, has produced a respectable body of literature which finds no place in the present list as above limited.

The members of the Scientific corps in 1865 were Robert Kennicott, H. M. Bannister, F. Bischoff, W. H. Dall, H. W. Elliott, Charles Pease, and J. T. Rothrock. In the scientific work done under the auspices of the Coast Survey (1871–'85) I was joined by Mark W. Harrington and Marcus Baker, of the Survey, and in 1880 by T. H. Bean, of the United States National Museum.

Publications by Bush, Dall, Elliott, Kennan, and others on material not connected with the explorations previously enumerated or relating wholly to Siberia are not included in the list.

GEOGRAPHY AND EXPLORATION.

(See also under Meteorology and Geology.)

Baker (Marcus). Boundary line between Alaska and Siberia.

Bull. Phil. Soc. of Wash., iv, pp. 123–133, 1881, with maps.

Dall (William Healey). Report on the operations of the Scientific Corps of the Western Union Telegraph Expedition during the season of 1865.

Proc. Chicago Academy of Sciences, i, pp. 31, 32. 1866.

——— Explorations in Russian America.

American Journal of Science, xlv, pp. 96–99. Jan., 1868.

——— Exploration of the interior of Russian America.

Mining and Scientific Press, San Francisco, Oct. 3 and 10, 1868.

——— Remarks on Alaska.

Proc. Cal. Acad. Sci., iv, pp. 30-37, 268, 293, 294. 1868.

——— Die telegraphen expedition auf dem Jukon in Alaska.

Petermann's Geogr. Mittheil., xv, pp. 361–365, with map. Oct., 1869.

——— Alaska and its resources.

Lee & Shepard, Boston, 8°, xii, 628 pp., 15 pl., 1 map. 1870.

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GRAPHIC REDUCTION OF STAR PLACES.*

BY

ERASMUS DARWIN PRESTON.

[Read before the Society January 4, 1896.]

Introduction.—The reduction of stars from their mean places at the beginning of the year, as given in the Catalogue, to their apparent places at any given time as found by observation, forms a very considerable part of the astronomical calculations made in the Coast and Geodetic Survey Office. This work is especially heavy in the latitude computations, and the labor has been accentuated in recent years by the attention given to the subject of latitude variation.

There are several ways of abridging the numerical calculations, depending on the relation between the number of stars observed and the number of nights on which observations are made. For example, if many stars are observed on two or three consecutive nights, differential formulæ may be applied by means of which the position having been obtained on any one date, that on succeeding dates may be found in about one-third the time required to get the first one. This method is given in Appendix No. 13, Coast and Geodetic Survey Report for 1888. When, however, observations are continued for a long time on the same stars, a condition that necessarily follows in researches on the variations of latitude, the reductions can be very much facilitated by a method employed in Appendix No. 2, Report of Coast and Geodetic Survey for 1892. This method, which con-

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sists in applying Bessel's numbers by differences, enables the computer to obtain the places for succeeding dates in about one-fourth the time required by the usual way. There are many cases, however, that do not fall strictly within the two foregoing categories, and to meet these the present graphic method has been devised. Its advantages are rapidity and ease of application. No numerical work being necessary, the fatigue attending such operations is entirely avoided. The accuracy of the method can be increased to any desirable extent by enlarging the scale. That adopted in the following description will, however, meet all the requirements of our present instruments and methods of observation. This method was originally devised to shorten the work in the latitude computations, and has therefore been used for declinations only, but following the same principles its application to right ascensions is easily made.

Description and Explanation.—Three general diagrams are given. The first (plate 7) shows the lines necessary for all the stars and is a reduced copy of the regular working sheet. The second and third (plates 8 and 9) are intended to show the construction for star No. 1381.* In plate 7 we have a graphic representation of the day numbers, A, B, C, D. The dimensions given refer only to the scale used in actual work and not to the illustrations, which have necessarily been reduced for convenience of publication.

On a quadrant drawn with a radius of 20 inches (plate 7) spaces are laid off equal to half degrees, corresponding to two minutes of right ascension. By this scale declinations to the nearest tenth of a degree and right ascensions to the nearest half minute may be indicated with the greatest facility. With the exercise of a little care, on a slightly increased scale the error in plotting the former need not be more than a minute or two of arc, and the latter may be plotted with a corresponding accuracy in time. Roughly speaking, the uncertainty of plotting the two functions may

* Catalogue of Stars for Observations of Latitude, Appendix No. 7, C. and G. S. Report for 1876.

be stated as about 6 seconds for the right ascensions and $1\frac{1}{2}$ minutes for the declinations. With the above stated dimensions the trigonometrical functions may be read off to three places, and the multiplication, by the graphical method, of these functions by the day numbers can be accomplished so that the greatest error will be only a few hundredths of a second of arc, which is abundantly sufficient for the reduction of star places for the ordinary latitude observations with the zenith telescope.

Concentric with the quadrant having a radius of 20 inches, another is drawn with a radius of 20.05 inches. This is for the purpose of finding 20.05 *cos* α. The two radii bounding the quadrants are subdivided into spaces of tenths of an inch. Each radius is therefore divided into 200 parts. Thus by estimating tenths of these divisions readings may be made to the two thousandth part of the radius. Through these points of division lines are drawn parallel to the radii, the result being that the entire surface is divided into small squares.

The divisions of the quadrant are numbered for declination in the center and for right ascension on either side. The degrees of declination are not indicated again on plates 8 and 9, as these are only intended to illustrate the method by application to a special case. The trigonometrical functions for the declination are used, however, on these sheets as they would appear on plate 7. The hours for the last argument are so chosen that the lines representing the star numbers a, b, c, d will fall horizontally. This facilitates their multiplication by the day numbers A, B, C, D, which are all plotted vertically. On the margin is indicated the space in which the right ascensions must be sought for the different star numbers a, b, c, d. A negative sign before the hours indicates that the trigonometrical function is to be taken in this sense.

The quantities A, B, C, D are plotted on the largest scale possible with the accompanying quadrant. This necessitates a slight change in the values of A, and they are laid down

on a scale ten times their real value; for example, the value on June 9 is 0.507, but is plotted as 5.07.

B may range from about $+ 9''$ to $- 9''$, so the marginal numbers are used, and the correct value of this quantity multiplied by any of the trigonometrical functions will be given by reading the result from the scale at the left.

C and *D* range from about $+ 20''$ to $- 20''$. They are plotted so that the radial value would be 20. Since both are symmetrical with reference to the horizontal line passing through the center, all values are plotted above the horizontal radius, and negative values in all day numbers are made apparent by using a curve in which dots are made for each individual day. The scale of dates is laid off in the middle of the sheet, and the value of any of the day numbers at a specified time may be found at the intersection of the corresponding curve, with the vertical line through the given date. By means of the horizontal lines the values of *A*, *B*, *C*, *D* may be transferred visually to the margin. For example, on June 9 we have the values

$$A = + 5.07, B = - 8.35, C = - 3.57, D = - 20.07.$$

Referring now to plate 8, we shall show the construction, *i. e.*, the graphic computation of the quantities

$$a' A = 20.05 \cos \alpha \times A.$$
$$b' B = - \sin \alpha \times B.$$
$$c' C = (\tan \omega \cos \delta - \sin \alpha \sin \delta) \times C.$$
$$d' D = \cos \alpha \sin \delta \times D.$$

It should be borne in mind, however, that in actual practice the method is very much shorter than would appear from the lines drawn in plate 8. For example, in finding the value of $a' A$, when we have once located the position of the right ascension, $16^h\ 33^m.5$ on the quadrant, it is seen by mere inspection that the quantity $20.05 \cos \alpha$ is equal to $- 7.38$. In fact it is not necessary to know the numerical value of this quantity, since it is to be multiplied by *A*, and it is only the final product that we care to determine.

We need only know that the value of a' is the line FG. This factor enters the computation as a line without reference to its numerical value. A fine thread being attached at the center O, and the other end being held by the hand at J, the intersection of this thread with the vertical line through the point of right ascension, G, gives at once the value of $a' A$, or — 3.74. No lines are actually drawn, but the final products are found by projecting selected points, with the eye, either horizontally or vertically until they meet the line of the thread. This visual projection is rendered easy and accurate by the small spaces into which the sheet is divided. Moreover, on the regular working sheet both the quadrants indicating right ascensions and declinations and the curves for the day numbers are drawn. The diagrams are separated for illustration and to avoid confusion in the construction lines, which in the regular work are never drawn. For comparison, the logarithmic computation, employing Bessel's numbers, is given on the following page for the apparent declination of star No. 1381.

GRAPHIC DETERMINATIONS.

Reductions in Declination.—Proceeding now to determine the quantities $a' A$, $b' B$, $c' C$, $d' D$ for star No. 1381, we shall indicate data and final results by full lines. Construction lines are dotted. Partial results, which are intermediate between the data and final results, such as the values of $\tan \omega \cos \delta$, $\sin \alpha \sin \delta$, etc., are shown in broken lines. The reduction is made from the mean place on January 0, 1895, to its apparent place on June 9, 1895.

The position of the star is (taking the nearest half minute in α):

$$\text{Right ascension} = \alpha = 16^{h}\ 33^{m}.5.$$
$$\text{Declination} = \delta = 53^{\circ}\ 7'.$$

First term.—To get $a' A = 20''.05 \cos \alpha \times A$ (see plate 8).

We seek the value of α in the quadrant marked (a and d) and read at once the value of $20.05 \cos \alpha$ or $F\,G$ on the outer one

of the arcs. The negative sign before 16 indicates that the cosine of the right ascension is minus. This quantity, which is — 7.38, is to be multiplied by the value of A on June 9. On this date we see, by inspection of plate 7, that A equals $+ 0.507 \times 10$ or the line $H\ I$. In order to multiply the two lines $F\ G$ and $H\ I$, I is projected to J. The point J is the intersection of a horizontal line through I and a vertical line at a distance of 10 units from the origin O. The point of intersection of the vertical through G and the line $J\ O$ determines the length of the line $K\ L$, which is equal to $F\ G$ multiplied by $H\ I$, or 20.05 $\cos a \times A$; therefore $a'\ A =$

STAR NO. 1381.—*Catalogue of Stars for Observations of Latitude.*

(Report of U. S. Coast and Geodetic Survey for 1876, Appendix No. 7.)

Reduction from mean to apparent declination.

		Log.	No.
$a = 16^h\ 33^m\ 41^s = 248°\ 25'$	$\sin a =$	9.9684n	— 0.930
$\delta = 53°\ 7'$	$\cos a =$	9.5657n	— 0.368
	$\sin \delta =$	9.9030	+ 0.800
	$\cos \delta =$	9.7783	+ 0.600

Terms	a' 20,052 $\cos a$	b' $-\sin a$	c' $\tan \omega \cos \delta$ $-\sin a \sin \delta$	d' $\cos a \sin \delta$
Computation.	*Logs* 1.3022 9.5657n	*Logs*	*Logs* *Logs* 9.6373 9.9684n 9.7783 9.9030 9.4156 9.8714n 0.2604 0.7437 + 1.004	*Logs* 9.5657n 9.9030
Log a' b' c' d'.....	0.8679n	9.9684	0.0017	9.4687n
" A B C D.....	9.7055	0.9215n	0.5521n	1.3026n
	0.5734n	0.8899n	0.5538n	0.7713
Nos. $a'A, b'B, c'C, d'D$.	— 3.74	— 7.76	— 3.58	+ 5.91
For June 9:				
Nos. a' b' c' d'....	— 7.38	+ 0.930	+ 1.004	— 0.294
" A B C D.....	+ 0.508	— 8.35	— 3.57	— 20.07

— 3.74, agreeing with the logarithmic computation previously given. This follows from the proportion

$$h\,J : h\,O :: L\,K : L\,O$$

or $$H\,I : 10 :: L\,K : F\,G.$$

Hence

$$L\,K = \frac{H\,I \times F\,G}{10},$$

which gives $L\,K$ in correct units, since the value of A, or 0.507, was plotted on a scale 10 times its true value.

When a number of stars are to be reduced for the same date, the point J applies to all, and the values of $a'A$ for the separate stars are the vertical lines included between the axis of abscissas and the line $J\,O$. The lines are, of course, vertically under the points on the arc corresponding to the right ascensions.

For the sake of uniformity in the process of multiplication, the day numbers A, B, C, D are always projected to the vertical scale at the right when finding the products $a'\,A$, $b'\,B$, $c'\,C$, $d'\,D$. It is evident that the same result would ensue by projecting the star numbers a', b', c', d' to the horizontal scale at the top, drawing the radial line and measuring the intercept obtained by projecting the day numbers to the left. For example, if G is projected to m'' and $m''\,O$ is drawn it will intersect the line $J\,I$ prolonged, in K'', giving $L''\,K'' =$ — 3.74, as before. The algebraic proportions may be written out similarly to those above. If G is projected to m' and the line $m'\,O$ is drawn it will intersect the line $J'\,I'$ prolonged, in K' giving $L'\,K' =$ — 3.74, as before. To avoid confusion with lines already given in the figure $G\,m'$ and $m'\,O$ are not drawn.

Without writing out the proportions it is quite evident that in the triangle $L'\,K'\,O$ the line $L'\,K'$ is $\frac{7.38}{20}$ of $L'\,O$, so that it is equal to $\frac{7.38}{20}$ of (2×5.05). Likewise in the triangle $L''\,K''\,O$ the line $L''\,K''$ is $\frac{7.38}{10}$ of $L''\,O$, and is there.

fore $\frac{7.38}{10}$ of 5.05; both of these being equivalent to the first construction, viz., 7.38×0.505.

In cases where the value of 20.05 *cos* α is represented by a line longer than ten units, extrapolation is avoided by plotting on a scale twice as large as that just used, which would make the point I fall at I'. I' is then to be projected to J', and the value of a' A is, as before, -3.74. If A is plotted on this scale nearly every value of 20.05 *cos* α will be shorter than the horizontal distance between O and the point to which I' is projected, or J', and the values of a' A will be vertical lines lying between J' and the center, so that the only extrapolation resorted to is that for values of a' between 20.00 and 20.05; but no sensible error would be introduced by following the first construction.

The scale at the left or right gives the result in correct units. This follows from the proportion

$$H'J' : H'O :: LK : LO$$

or $\quad HI' : H'O :: LK : FG$, as previously given.

Hence

$$LK = \frac{HI' \times FG}{H'O} = \frac{(0.505 \times 20)}{20}(-7.38) = -0.505 \times 7.38.$$

Second term.—To get b' $B = -$ *sin* $\alpha \times B$ (see plate 8).

In this case we make use of the inner quadrant or the one described with a radius 20.

Find the right ascension in the quadrant marked (b and c). The sine for radius 20 is equal to $M N$ or -0.930×20. The value of B on June 9 is $H P$ or -8.35. Project P to Q. The intersection of the vertical line through N with the line O Q gives the point R, and the distance R S, read from the scale, gives 7.76, which is the value of *sin* $\alpha \times B$.

In actual work the thread being held at Q and the point N being selected by inspection, the position of R and its value on the scale are read off at sight without either drawing

lines or writing figures. This advantage, of course, applies to all determinations by this method.

We have the proportion

$$H' Q : H' O :: S R : S O$$

$$\text{or} \qquad H P : H' O :: S R : M N.$$

Hence

$$S R = \frac{H P \times M N}{H' O} = \frac{(-8.35)\ (-0.930 \times 20)}{20} = +7.76.$$

The value of $b' B$ is then -7.76.

As in the case of $a' A$, all reductions for stars on June 9 have one point in common (here Q), and the values of $\sin \alpha \times B$ will appear as vertical lines included between the line $Q\ O$ and the axis of X.

In giving the values of the trigonometrical functions the factor 20 is always written, as that is the number of units in the radius. The natural value of the function is, of course, the first factor.

Third term.—To find $c'\ C = (\tan \omega \cos \delta - \sin \alpha \sin \delta)\ C$, (see plate 8).

Here $\omega = 23° 27' =$ obliquity of ecliptic

and $\tan \omega = 0.434$

We first find the second term of the parenthesis. By the same construction as was used for $b' B$ the sine of α is $-0.930 \times 20 = M N$. The sine of δ is $T\ V$ or $+0.800 \times 20$. These quantities must be multiplied in such a way that the product is a horizontal line, viz., by projecting N to U and noting the point where the line $U\ O$ intersects the horizontal line through V. The line $X\ Y$ is equal to -14.88 or -0.744×20. We therefore have for the second term of the parenthesis on the actual scale

$$\sin \alpha \sin \delta = -0.744 \times 20 = -14.88.$$

This follows from the proportion

$$q\,U : q\,O :: X\,Y : X\,O$$

or $$M\,N : q\,O :: X\,Y : T\,V.$$

Hence

$$X\,Y = \frac{M\,N \times T\,V}{q\,O} = \frac{\sin \alpha \sin \delta}{q\,O} = \frac{(-0.930 \times 20)(0.800 \times 20)}{20}$$
$$= -0.744 \times 20 = -14.88.$$

We now find the first term of $c' = \tan \omega \cos \delta$. The cosine of δ is $X\,V$ or $+ 0.600 \times 20 = 12.00$. Project V to W; draw $O\,W$. Where this intersects the horizontal line through Z determines the distance $Z\,E$, which is

$$\tan \omega \cos \delta \text{ or } + 0.260 \times 20 = + 5.20.$$

The sum of the two terms of c' is therefore $(5.20 + 14.88)$ or $1.004 \times 20 = 20.08$. The distance $Z\,O$ is 20 times the natural tangent of the obliquity of the ecliptic, and the line through Z is drawn once for all, as it is common to all the stars. In order to have the two terms of c' on the same scale, Z is taken at a distance from the axis of X of $20 \times 0.434 = 8.68$.

So that we have the proportion

$$q\,W : q\,O :: Z\,E : Z\,O$$

or $$X\,V : q\,O :: Z\,E : \tan \omega \times 20.$$

Hence

$$Z\,E = \frac{X\,V \tan \omega \times 20}{q\,O} = \frac{(0.600 \times 20)}{20}\ (\tan \omega \times 20)$$
$$= 0.600 \times 0.434 \times 20 \qquad = 0.260 \times 20.$$

The value of $Z\,E$ is laid off on the prolongation of $X\,Y$, giving the point A, where

$$X\,A = X\,Y + Y\,A = (0.260 + 0.744) \times 20 = +1.004 \times 20;$$

the first term of the value $c'C$ being positive and the second

term negative, their difference is $+ 20.08$. This is to be multiplied by the value of C on June 9, which is -3.57; project B to C; draw $C\ O$. Where the vertical line through A meets $C\ O$ prolonged gives the point D and the line $D\ D'$ is the product $c'\ C$ or $(\tan \omega \cos\delta - \sin \alpha \sin \delta) \times C$ or -3.59. This follows from the proportion

$$H'\ C : H'\ O :: D'\ D : D'\ O$$

$$\text{or} \qquad H\ B : H'\ O :: D'\ D : X\ A.$$

Hence

$$D'\ D = \frac{H\ B \times X\ A}{H'\ O} = \frac{-3.57\ (1.004 \times 20)}{20} = -3.59.$$

If $\sin \alpha \sin \delta$ is positive, the value of $Z\ E$ is laid off to the left of Y, the construction being otherwise the same.

Fourth term.—To find $d'\ D = \cos \alpha \sin \delta \times D$ (see plate 8).

Seeking the right ascension in the quadrant marked (a and d) we find $\cos \alpha$ for radius 20 to be $f\ g$ or -0.368×20. This must not be confounded with -0.369×20, which is on the same scale the value of $20.05 \cos \alpha$ and which is measured on the outer circle. The sine of δ is $T\ V$ or 0.800×20. Project g to m. Where the line $m\ O$ intersects the line $X\ V$ already drawn, determines the point n. $X\ n$ is then the value of $\cos \alpha \sin \delta$ or $-0.294 \times 20 = -5.88$.

We have

$$q\ m : q\ O :: X\ n : X\ O$$

$$\text{or} \qquad f\ g : q\ O :: X\ n : T\ V.$$

Hence

$$X n = \frac{f g \times T\ V}{q\ O} = \frac{(-0.368 \times 20)\ (+0.800 \times 20)}{20} =$$

$$-0.368 \times 16.00 = -5.88.$$

The line $X n$ is now to be multiplied by -20.07, the value of D on June 9, which we find equal to the line Hp.

Project p to a; draw $a\ O$. The intersection of $a\ O$ with a vertical line through n gives the point t, and we have $r\ t$ equal to $\cos \alpha \sin \delta \times D$ or to $+\ 5.91$.

We have

$$H'\,a : H'\,O :: r\,t : r\,O$$

or $$H\,p : H'\,O :: r\,t : X\,n.$$

Hence

$$r\,t = \frac{H\,p \times X\,n}{H'\,O} = \frac{(-\ 20.07)\ (-\ 0.294 \times 20)}{20} = +\ 5.91.$$

Reductions in Right Ascension (see plate 9). In the reductions for right ascension the curves for the day numbers $A\ B\ C\ D$ are used as already plotted, and the star numbers are so constructed that the lines representing a, b, c, d, fall horizontally.

This may be readily effected, since they all depend on at least three quantities, and these may be multiplied in such a way as to give the resulting line either desired direction.

The inner quadrant already drawn holds good for the right ascensions, as already used for declinations. In seeking the trigonometrical functions of δ, however, the degrees count in the opposite direction; to facilitate this, each degree has its complement written opposite.

In finding the values of a and b, it is necessary to use the value of $\tan \delta$. This is obtained, where the declination is less than 45°, from the horizontal line at a distance of 10 units from the origin. A line drawn from the given degree to the point O intersects it at a vertical distance from the origin equal to ten times the natural tangent of the angle. This construction gives us three units in the value. We may now proceed to the final result by using this value, or two units may be employed and the construction carried forward on the scale used for arcs beyond 45°. Both these methods will be indicated later.

For comparison, the usual logarithmic computation is here given.

STAR No. 1381.—*Catalogue of Stars for Observations of Latitude.*

(Report of U. S. Coast and Geodetic Survey for 1876, Appendix No. 7.)

Reduction from mean to apparent right ascension.

	Log.	N
$\alpha = 16^h\ 33^m\ 41^s = 248°\ 25'$	$\sin\alpha = 9.9684n$	$= -0.930$
$\delta = \quad 53°\ 7'$	$\cos\alpha = 9.5657n$	$= -0.368$
	$\tan\delta = 0.1247$	$= +1.33$
	$\sec\delta = 0.2217$	$= +1.67$

Terms	a $3^s.073 + 1.337 \times \sin\alpha \tan\delta$	b $\frac{\cos\alpha \tan\delta}{15}$	c $\frac{\cos\alpha \sec\delta}{15}$	d $\frac{\sin\alpha \sec\delta}{15}$
Log 1.337	0.1261			
" $\sin\alpha$	9.9684n			
" $\tan\delta$	0.1247			
Sum logs	0.2192n			
No	—1.656			
No	3.073	8.8239	8.8239	8.8239
sum	1.417	9.5657n	9.5657n	9.9684n
		0.1247	0.2217	0.2217
Logs $a\ b\ c\ d$	0.1514	8.5143n	8.6113n	9.0140n
" A, B, C, D	9.7055	0.9215n	0.5521n	1.3026n
" aA, bB, cC, dD	9.8569	9.4358n	9.1634	0.3166
Nos. " " " "	+0.719	+0.273	+0.146	+ 2.073
$A\ B\ C\ D$	+0.507	—8.35	—3.57	—20.07

Construction of Auxiliary Lines.—In order to find the tangents from 0° to 45° the line $j\,p$ is used. These values may be reduced either graphically or mentally. For values of the declination between 45° and 87° the tangents are read from the lines t, t', t'', t''', and t^{iv} of plate 7. The method of construction enables us to find the values for every minute of arc. The curve t applies to declinations from 45° to 50°; t' extends from 50° to 60°, etc. The units in the degrees are given by the vertical scale, and each small square represents vertically 6 minutes of arc. The tangents are the horizontal lines included between the axis of ordinates and the

respective curve—*e. g.*, the tan of 68° is 2.48, the tan of 85° is 11.43, etc.

The secants which are necessary in finding the values of c and d are obtained from the curves S', S'', S''', etc. To facilitate their multiplication by $sin\ \alpha$ and $cos\ \alpha$, the curves are drawn so that the secants are vertical lines and count from the axis of abscissas. From 45° on they are found in a similar manner to the tangents, but below 45° the curve S is used, which gives three places with sufficient accuracy. Referring to the case before cited, where the tangent of an angle less than 45° is to be employed, let us suppose the case where $\delta = 25°$. The tangent by the construction already indicated would be found (plate 9) on the line $j\ p$ at p', where $j\ p' = 0.466$.

If we only desire two places, instead of reading the value from the line $j\ p$ it may be read from the horizontal line at a distance of one unit from the axis of abscissas and we get 0.47. This being on the same scale as the tangents beyond 45°, the subsequent proceeding is in every way similar. Should three places be desirable, project p' to p''. Then $p''\ p''' = 10 \times sin\ \alpha\ tan\ \delta = 4.33$, and the true value of 1.337 $sin\ \alpha\ tan\ \delta$ required in the construction of $a\ A$ will be found by projecting p'' to the axis of ordinates, and thus determining the line $p^{iv}\ p^{v} = 0.58$, $j\ k'$ being made $= j\ o \times 0.134$.

The same result by an analogous construction follows by taking both $tan\ \delta$ and the factor 1.337 in their true proportion. This is not shown in the figure, to avoid a multiplicity of lines and letters. It may be added, however, that inasmuch as the trigonometrical function by which $tan\ \delta$ is multiplied can never exceed unity, two places are sufficient for small values of δ, and especially in view of the fact that in the quantity $a\ A$ we have the factor A, which is small, and in $b\ B$ the quantity 15 appears in the denominator, both tending to reduce the number of necessary places.

First term.—To find $a\,A = (3^s.073 + 1^s.337 \sin\alpha \tan\delta) \times A$ (see plate 9).

The tangent of 53° 7′ is the line $c\,d = 1.33$. In order to verify this value reference must be had to plate 7; but in the regular work the determinations are made on the same sheet on which the curves are drawn. The sine of $16^h\ 33^m.5$ is $a\,b = -0.930 \times 20$. Project b to f and draw $f\,o$. The vertical line $g\,h$, at a distance from the axis of ordinates equal to $c\,d$ and included between the line $f\,o$ and the axis of abscissas, is the product of $\sin\alpha \tan\delta$, or 1.24.

This follows from the proposition

$$e\,f : e\,o :: g\,h : g\,o$$

$$\text{or} \qquad a\,b : e\,o :: g\,h : c\,d$$

$$\text{Hence} \qquad g\,h = \frac{a\,b \times c\,d}{e\,o} = \frac{-0.930 \times 20 \times 1.33}{20} = -1.24.$$

Draw $k\,o$ so that $j\,k = 1.337$ times $j\,o$. The horizontal line $l\,m$, passing through the point h and included between the axis of ordinates and the line $k\,o$, is therefore equal to the quantity $1.337 \sin\alpha \tan\delta$, or -1.66. This follows from the fact that in the triangle $j\,o\,k$ each abscissa is 1.337 times the corresponding ordinate. The total value of the quantity within the parenthesis, or a, is therefore $3.07 - 1.66$, or $+1.41$.

This quantity is to be multiplied by the value of A on June 9, or 0.507. The necessary lines for the multiplication of this quantity by any factor have already been drawn in the case of the declinations, and in actual work their application to the right ascensions is directly made without new construction. The method is as follows: The value of A projected to the line $p\,n$ gives the point q, and a vertical line, $r\,s$, included between $q\,o$ and the axis of abscissas, and at a distance from the origin equal to 1.44, gives the value of $a\,A$, or $+0.71$.

We therefore have

$$a\,A = (3^s.073 + 1^s.337 \sin\alpha \tan\delta) \times A = +0^s.71.$$

Second term.—To find $b\,B = \frac{1}{15} \cos \alpha \tan \delta \times B$ (see plate 9).

The cosine of α is the line $u\,v = -0.368 \times 20$. The tangent of δ is $c\,d = o\,g = 1.33$. Project v to v' and draw $v'\,o$. The intersection of this line with the vertical through d gives the point s'. We then have $g\,s' = \cos \alpha \tan \delta = -0.49$. Draw $o\,x$ so that $j\,x = \frac{10}{15} \times j\,o$. The intersection of a horizontal line through s' with the line $x\,o$ gives the point s'' and $s''\,y = \frac{10}{15} \cos \alpha \tan \delta = -0.33$. The value of B on June 9 is -8.35. This distance laid off on the line $p\,n$, or, which is the same thing, the ordinate for June 9 being projected to the vertical at a distance of 10 units from the origin, gives the point Z. The intersection of a vertical line through s'' with the line $Z\,o$ gives the point Z' and the distance

$$Z'\,Z'' = \frac{1}{15} \cos \alpha \tan \delta \times B = +0.27.$$

The object in laying off $j\,x = \frac{10}{15}\,j\,o$ is to secure one more decimal place in the value of b. The correct value in the final result is obtained in the multiplication by B, since the construction gives us $\frac{835}{1000}$ of $\frac{10}{15} \cos \alpha \tan \delta$.

The line $x\,o$ is used in the construction of $c\,C$ and $d\,D$ as well as $b\,B$.

Introducing the factor $\frac{10}{15}$ serves the double purpose of giving one more decimal place, thus increasing the accuracy, and also of restoring the final result to the correct scale after multiplying by B.

Third term.—To find $c\,C = \frac{1}{15} \cos \alpha \sec \delta \times C$ (see plate 9).

The secant of the declination is the line $A\,B = \sec 53° \,7'$ $= +1.67$. For verification see plate 7. The intersection of

a horizontal line through B with the line $x\,o$ already drawn gives $A'\,B'$, which is

$$\frac{10}{15} \sec \delta = 1.11$$

$$\cos \alpha = -0.368, \text{ as before.}$$

Project B' to B''.

The intersection of a horizontal line through v with the line $B''\,o$ gives the distance A''

$$= \frac{10}{15} \cos \alpha \sec \delta = -0.408.$$

The value of C on June 9 is -3.57.

The intersection of a vertical line through the extremity of A'' with the line $V''o$ determines the line p, which is equal to $+0.15$.

$$\text{Hence } P = \frac{1}{15} \cos \alpha \sec \delta \times C = +0.15.$$

As in the case of $b\,B$, the true value of the last result is given by multiplying finally by 0.357 instead of 3.57; this corrects for the artifice employed of magnifying the first partial result, viz., $\frac{1}{15} \sec \delta$, in order to secure one more decimal place. In the case of $c\,C$, since both $\cos \alpha$ and $\sec \delta$ are vertical lines, the latter is multiplied by $\frac{10}{15}$ in order to change its direction and thus facilitate its multiplication by $\cos \alpha$.

Fourth term.—To find $d\,D = \frac{1}{15} \sin \alpha \sec \delta \times D$ (see plate 9).

As in the previous case, we have $\frac{10}{15} \sec \delta = A'\,B' = 1.11$, and by previous construction $\sin \alpha = a\,b = -0.930 \times 20$.

The intersection of a horizontal line through b with the line $B''o$ gives the line $M\,N$, by which we have

$$M\,N = \frac{10}{15}\, sin\ \alpha\ sec\ \delta = -1.03.$$

The value of D on June 9 is -20.07.

This value is projected to a vertical line at a distance of 10 units from the axis of ordinates, thus correcting for the factor 10 introduced in the value $M\,N$.

A vertical line through N intersects the line $N'o$ at a distance $M'\,p' = 2.07$ from the axis of abscissas, and we have finally

$$M'\,P' = \frac{1}{15}\, sin\ \alpha\ sec\ \delta \times D = +2.07.$$

Attention may be called, in conclusion, to the striking manner in which the principal characteristics of the values A, B, C, and D are brought out in the graphic representations. By reference to plate 7 it will be noticed that both A and B have two large maxima and minima during the year. In addition to this, each curve is marked by a number of smaller maxima and minima. C and D, being dependent on the cosine and sine of the sun's longitude, present but one maximum and one minimum.

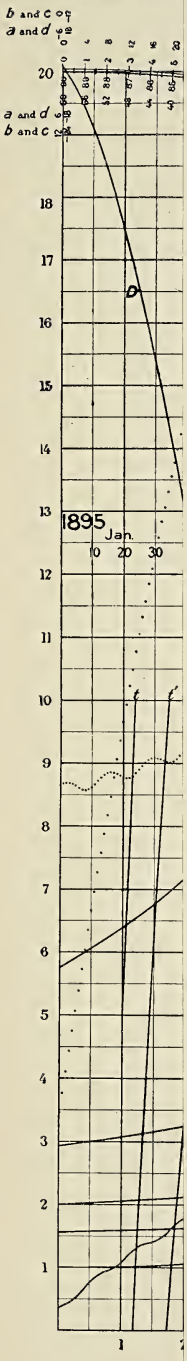
The general increase of A is the result of the term depending on the sine of the longitude of the moon's ascending node, combined with the value of t, which increases much more rapidly than the sine term decreases. The term depending on twice this function being of the opposite sign would tend to diminish this effect, but as it is only about one per cent of the first term its influence is barely perceptible.

The general decline of B, negatively, is caused by the cosine of the function mentioned, and is seen to be about three-fourths of one second, as the formula requires. As in the case of A, the function depending on the double angle modifies this to some extent.

The two major maxima and minima in both A and B are produced by the terms depending on twice the sun's true

longitude, the double angle accounting for the four appearances of the extreme values. It will be noticed that the range in A is about 0.05 and in B about $1''$, as demanded by the formula. In this connection it should be remembered that A is plotted on a scale 10 times its true value.

The minor maxima and minima in A and B show the effect of the term depending on the moon's mean longitude. The range for A is about one-half as much as that for B. There are twenty-seven maxima and minima during the year in each curve, which corresponds to twice the moon's motion.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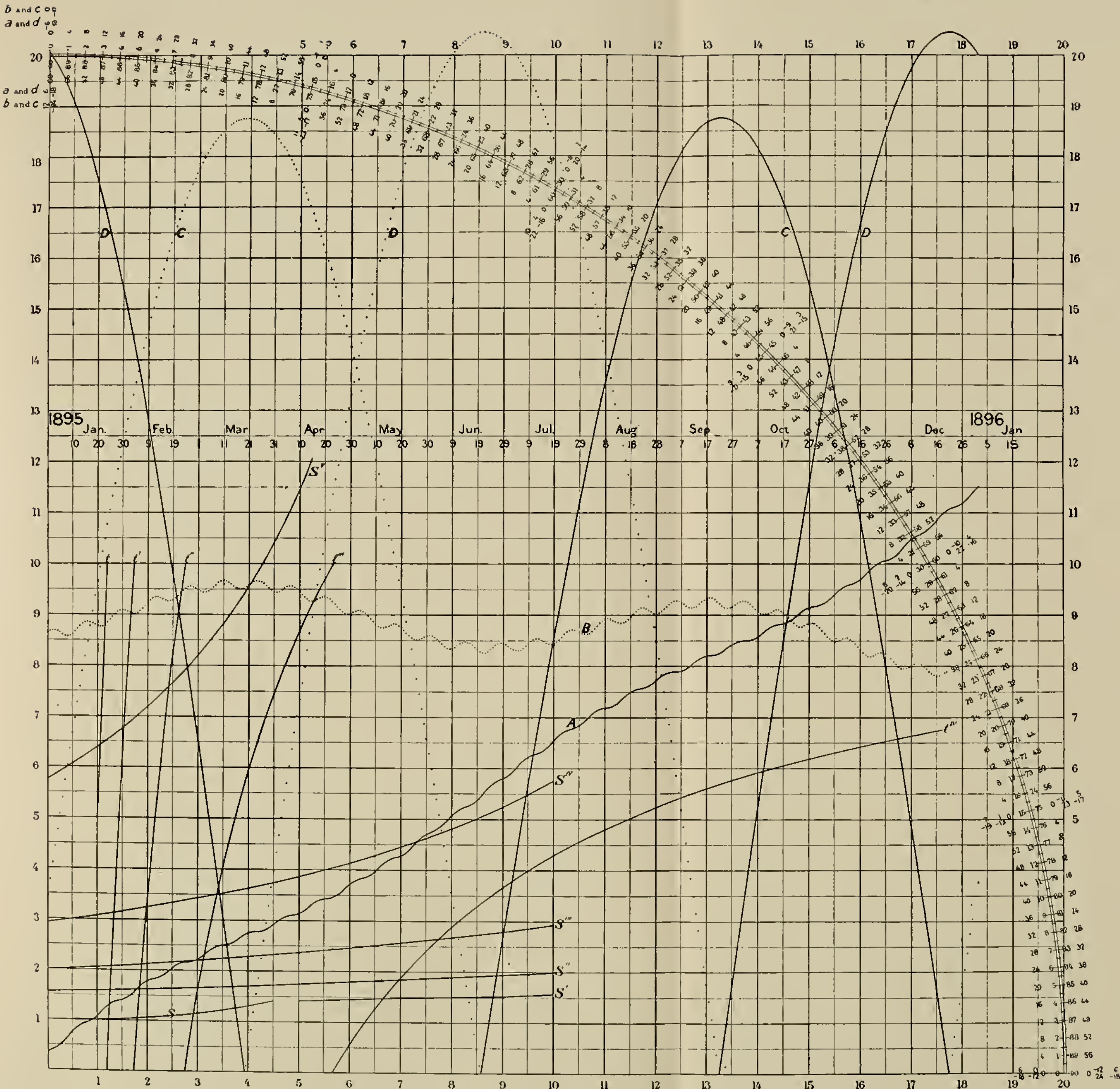
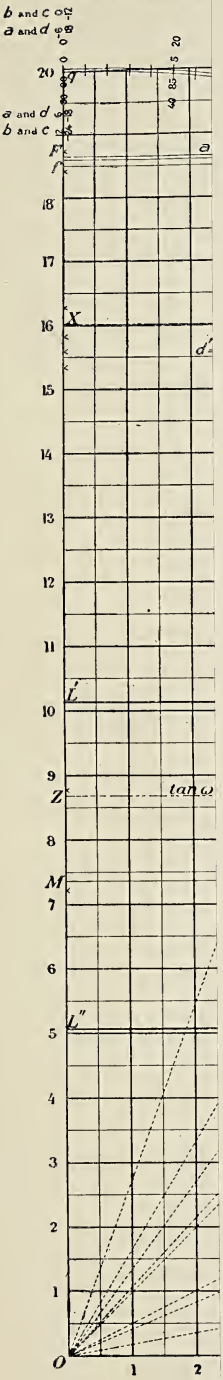
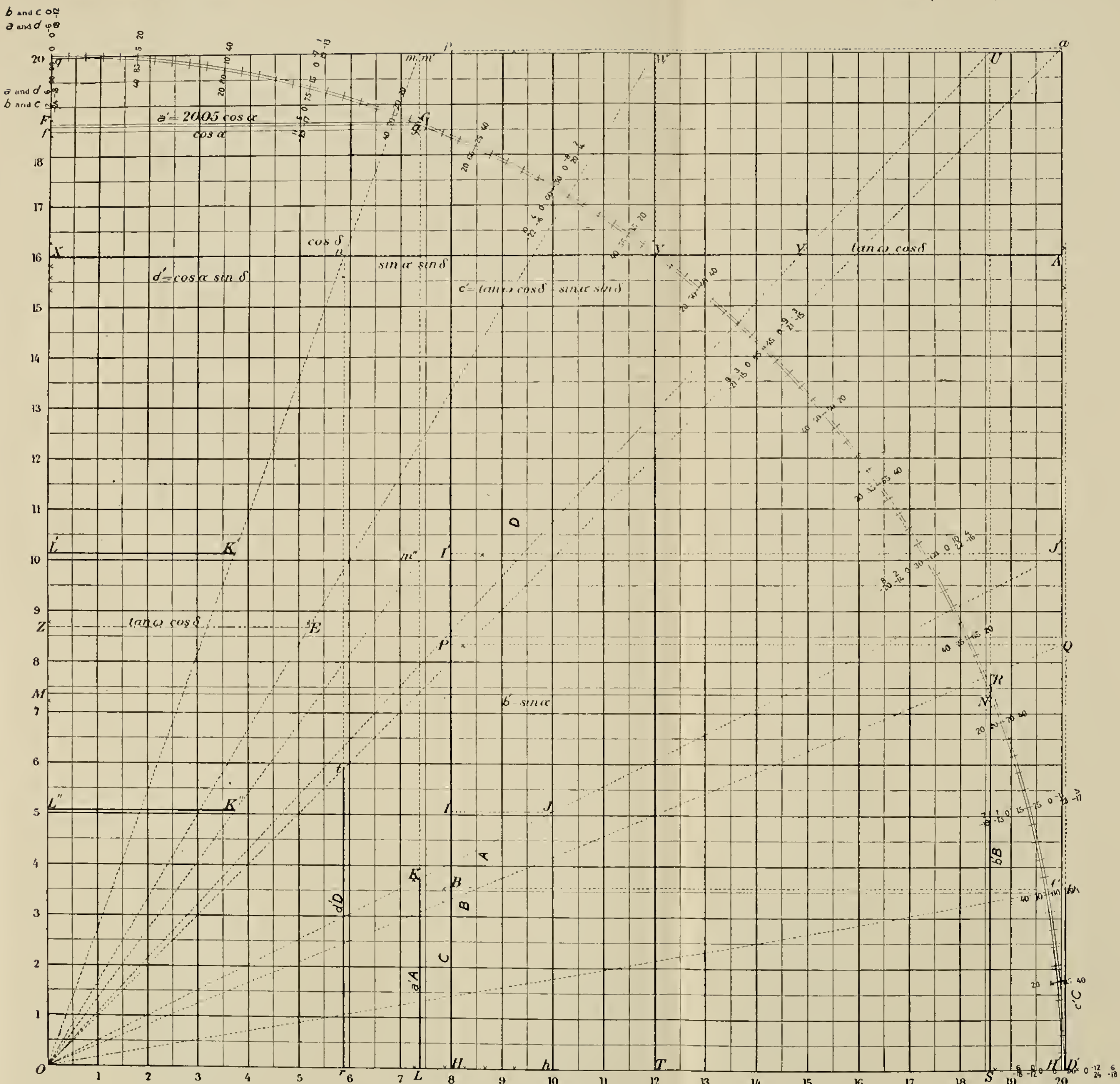


PRESTON—GRAPHIC REDUCTION OF STAR PLACES

CURVES FOR DAY NUMBERS, TANGENTS, AND SECANTS

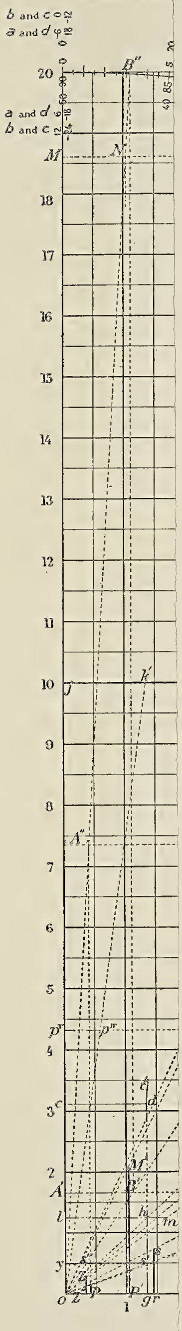
BULL. PHIL. SC





PRESTON—GRAPHIC REDUCTION OF STAR PLACES

REDUCTIONS IN DECLINATION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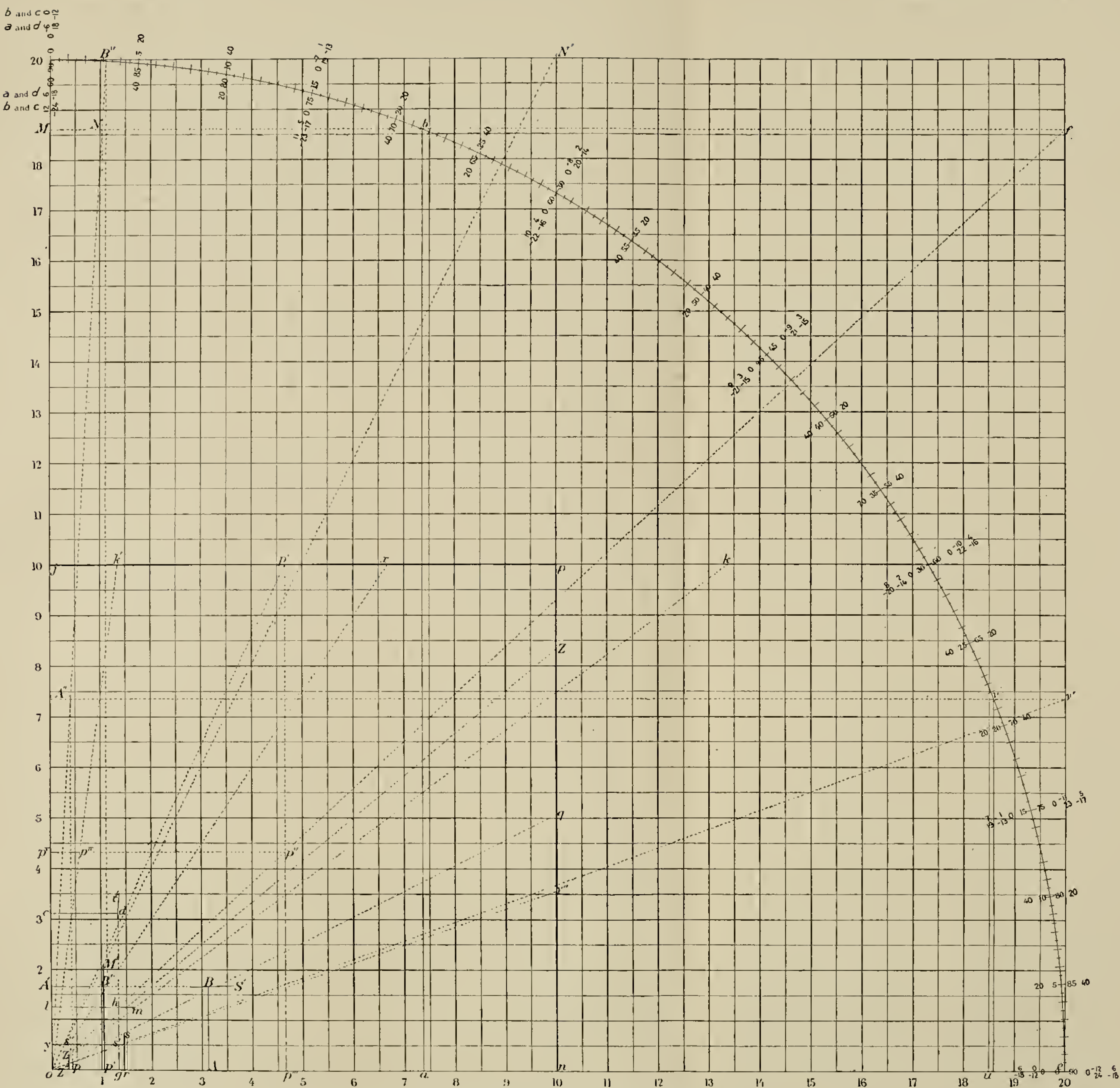

PRESTON—GRAPHIC REDUCTION OF STAR PLACES

REDUCTIONS IN RIGHT ASCENSION

CHEMISTRY IN THE UNITED STATES.

BY

F. W. Clarke.

THE ANNUAL PRESIDENTIAL ADDRESS,

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In the history of science, from whatever point of view we may consider it, the several branches develop according to a natural order. The more obvious things attract attention first, the less obvious are recognized later. Plants, animals, stones, and stars are studied even by savages, but the hidden forces of nature, governed by laws which can be utilized for man's benefit, escape discovery until civilization is far advanced, and even then are revealed but slowly. At first each department of knowledge is purely empirical, a mass of facts without philosophical connection; but sooner or later speculation begins, the scattered evidence is generalized, and an organized science is born. The study of concrete facts, the recognition of our surroundings, precedes the study of relations.

Among the sciences chemistry is one of the youngest. As an organized branch of systematic knowledge it has little more than completed its first century. Before the time of Robert Boyle it was hardly better than empiricism. At first a few scattered facts were recognized, involving transformations of matter. Some of these were applied in the arts, as in metallurgy and in medicine, and their generalization led simply and naturally into alchemy, with its search for the

philosopher's stone, the universal solvent, and the elixir of life. There was no chemistry in the modern sense of the term, but only a group of visionary speculations which foredoomed their devotees to failure. In these failures, however, Truth revealed herself, discoveries were made other than those which were expected, and the foundations of a new science were laid. It was more than forty years after the landing of the Pilgrims at Plymouth when Boyle announced the true definition of a chemical element, and the discovery of oxygen was not made until over a century later. The history of modern chemistry and the history of the United States begin at nearly the same time.

In America, as in the world at large, the development of science followed along the natural lines. A new country had no time for abstractions, such as chemical studies were in the early days, and only the more obvious branches of investigation received much notice. Botany and zoölogy flourished to some extent, and even mineralogy had able students; for the resources of an unexplored continent could not be ignored. Astronomy, too, was somewhat cultivated, but because of its usefulness in the measurement of time and in navigation, rather than for its interest as an intellectual pursuit. The practical side of science was necessarily and properly foremost, and this fact is nowhere more apparent than in the physical researches of men like Franklin and Rumford. The obvious and the useful came first; philosophy, theory, might wait until men had more leisure. So, while chemical discoveries were rapidly multiplied in Europe, little advancement could be recognized here. Even that little was utilitarian, and chemistry in this country was first brought into general notice through its relations to medicine and pharmacy and through the agency of medical schools.

Prior to the year 1769 chemistry had no independent existence in the work of American colleges. It was taught, if indeed it was taught at all, only as a subordinate branch of natural philosophy. But in the year just named Dr. Benjamin Rush was appointed to a chair of chemistry in the medi-

cal department of the University of Pennsylvania, an event which marks the first recognition of the science in the United States by any institution of learning. Other medical schools soon followed the example thus set, and chemistry took its place as a regular subject for study. Rush, however, was not specifically a chemist; he had indeed been a pupil of Black in Edinburgh; but he carried out no chemical investigations, and added nothing to the sum of chemical knowledge. His high reputation was won in other fields, but as the first professor of chemistry in America he occupies a historical position.

In 1795 the trustees of Nassau Hall, now Princeton University, elected Dr. John Maclean professor of chemistry. Other colleges soon followed the lead of Princeton, and within a very few years chemical science was well established as a distinct branch of study in many American institutions. The teaching, however, was wholly by textbooks and lectures, the laboratory method was unknown, and the teacher commonly divided his attention between chemistry and other themes. There were professors of chemistry and natural philosophy, of chemistry and natural history, but rarely, if ever, professors of chemistry alone. Moreover, little time was given to the subject; the classics and mathematics overshadowed all other studies, and the pupil learned hardly more than a few scattered facts and the barest outline of chemical theory. When we note that today Harvard University employs twenty-two persons—professors, assistant professors, instructors and assistants—in chemistry alone, we begin to realize the great advance which has been made in the teaching of science since the days of Maclean, Hare, and the elder Silliman.

In 1794 Joseph Priestley, the famous discoverer of oxygen, driven from his English home by religious persecution, sought refuge in America. He took up his abode at Northumberland, in Pennsylvania, where he died in 1804, and where his remains lie buried. His coming greatly stimulated the growing interest in chemistry upon this side of the Atlantic, for Priestley entered at once into close relations with many

American scholars, and took an active part in the work of the American Philosophical Society at Philadelphia. At Northumberland he completed his discovery of carbon monoxide, and made some of the earliest experiments upon gaseous diffusion; but unfortunately much of his time was devoted to theory, and to defending, against the attacks of Lavoisier's followers, the moribund doctrine of phlogiston. Priestley's discovery of oxygen was the corner-stone of chemical science; but the discoverer, great as an experimentalist, was not successful as a philosopher, and he never realized the logical consequences of his achievement. To the day of his death he opposed the new chemical philosophy, and clung to the obsolete ideas of an earlier generation.

During the first quarter of the present century the progress of chemistry in the United States was slow. It is not my purpose to discuss in this address the details of its advancement, for that work has already been exhaustively done by another; * still, several events happened which deserve notice here. First, Robert Hare, in 1802, invented the oxy-hydrogen blow-pipe. With that instrument, in following years, he succeeded in fusing platinum, silica, and about thirty other refractory substances, which had hitherto resisted all attempts at liquefaction. But few men have given a greater extension to our experimental resources. The calcium light and the metallurgy of platinum are among the direct consequences of Dr. Hare's invention. Secondly, in 1808, Professors Silliman and Kingsley, of Yale College, published their account of the meteorite which fell at Weston, Connecticut, the year previous. This paper attracted wide-spread attention, and drew from Thomas Jefferson the oft-quoted remark, "That it was easier to believe that two Yankee professors could lie than to admit that stones could fall from heaven." The analysis of the meteorite was the work of Silliman, and was among the earliest of its kind. It was

*Benjamin Silliman, Jr. "American Contributions to Chemistry." American Chemist, August, September, and December, 1874. An address at the "Centennial of Chemistry.

done with appliances such as a modern high school would despise, and without the aid of any manual of analytical chemistry; and its merit is due partly to the fact that it was well done, and partly to the way in which great difficulties were overcome. In weighing the work of the early investigators we must remember that they lacked the resources which are so easily commanded nowadays, and that the methods of research had not been reduced to system. Their success was in spite of disadvantages which would baffle most men, there was less encouragement than now in the way of popular applause, and their efforts are therefore all the more praiseworthy. Today scientific investigation is an established art, its ways are well worn and well trodden, and although the highest achievements are as difficult of attainment as ever, even a beginner may hope to accomplish something.

During these early years much attention was paid by American chemists to the study of minerals, for rich new fields were open; and in 1810 Archibald Bruce began the publication of "The American Mineralogical Journal," of which four numbers were issued. This was probably the first attempt to publish in this country a magazine devoted entirely to science and supported wholly by native contributions. As early as 1811 there was a Columbian Chemical Society in Philadelphia, and in 1813 a volume of its "Memoirs" appeared. In 1817 the "Journal of the Academy of Natural Sciences of Philadelphia" was started, and the next year saw the birth of Silliman's "American Journal of Science." The last-named periodical, a classic among scientific serials, was for sixty years the chief organ of American chemistry, and even yet, despite the rivalry of more specialized journals, it contains a fair proportion of chemical contributions. The first American to publish a systematic treatise on chemistry was Professor John Gorham, of Harvard College, whose "Elements of Chemical Science," in two octavo volumes, appeared in 1819. The work was well received, and was an excellent one for its day.

The period from 1820 to the outbreak of the civil war was one of steady progress in America, both as regards scientific research and in the development of institutions. Colleges were founded, societies were organized, there were better facilities for work, and the general appreciation of science became greater; but, for the reasons which were stated at the beginning of this address, the so-called natural sciences rather took the lead, and there was more activity among geologists and zoölogists than in the field of chemistry. Many States organized surveys, the General Government sent out exploring expeditions, and so geology and natural history received a patronage in which chemistry had little or no share. The chemists were mainly dependent upon their own resources and got along as best they could. Still, their number increased, their published investigations became more numerous, and their services were in greater demand both commercially and in the work of instruction.

At first the would-be chemist had to make his own pathway. Chemistry was taught in the colleges, not as a profession to be followed, but as a minor item in that ill-defined agglomeration of knowledge which in those days was called "a liberal education." In 1824, however, the Rensselaer Polytechnic Institute, at Troy, was founded, and a new era in scientific education began. In 1836 Dr. James C. Booth opened a laboratory in Philadelphia for instruction in practical and analytical chemistry, and in 1838 Professor Charles T. Jackson did the same thing in Boston. Chemistry could now be studied in something like a systematic manner, but the students who were able to do so went abroad, at first to London, Edinburgh, and Paris, and later to the famous laboratory of Liebig, in Germany. The impulse toward foreign study continues to our own day, even though American facilities have increased enormously and a good chemical training can now be obtained at home.

The decade from 1840 to 1850 was a period of great advancement in American science, and several events of the utmost importance occurred. In 1829 James Smithson, an

Englishman, bequeathed his property to the United States to found in Washington "an institution for the increase and diffusion of knowledge among men," and in 1846 his project was realized. The Smithsonian Institution was established; and under the direction of Joseph Henry it became at once a center of scientific influence and activity. Smithson, it will be remembered, was a chemist and mineralogist, and it was therefore eminently proper that the institution which bore his name should from the very beginning maintain a chemical laboratory. Furthermore, in the earlier years of its history the institution provided several courses of popular lectures upon chemistry; it has subsidized some chemical investigations, has published original researches, and it has issued a number of useful works in the way of special reports, volumes of physical constants, and bibliographies. Although its energies have been more conspicuously exerted in the fields of zoölogy, anthropology, and meteorology, it has done much for chemical science. The subjects which interested its founder have never been neglected. In the history of American chemistry the Smithsonian Institution plays an honorable part.

In 1847 and 1848 the Sheffield and Lawrence scientific schools were founded, the one at New Haven, the other under the protecting shelter of Harvard College. In the one, chemistry was taught by J. P. Norton and the younger Silliman, while Horsford conducted the laboratory at Cambridge. The much older Polytechnic Institute at Troy had developed mainly as a school of engineering, so that the two new institutions practically stood by themselves as the only higher schools of chemistry—schools in which professional chemists could receive a thorough training—within the limits of the United States. Their influence soon began to be felt, their graduates went forth to take important positions, the stimulus to scientific studies spread to the colleges, and the chemist became recognized as the representative of a new learned profession. Law, medicine, and divinity no longer formed a class by themselves; other branches of scholarship were to take rank with them.

In 1846 Agassiz came to America, bringing with him the research method as a method of education. Himself a zoölogist, his influence as a teacher was evident in all directions, and chemistry shared in the new impulse. There were many pupils of Liebig and Wöhler in the United States—men well imbued with the spirit of the new education—and to them the coming of Agassiz was a reinforcement and an inspiration. The old college curriculum was compelled to expand, and the true conception of a university began to be recognized on this side of the Atlantic. In 1848 the American Association for the Advancement of Science was organized, and science received a national standing which the local academies and societies could never have given it. The influence of the Association upon chemistry will be considered later.

In 1850 Josiah P. Cooke was elected professor of chemistry in Harvard College. He had received his bachelor's degree only two years earlier, and during his student days no chemistry had been taught to Harvard undergraduates. Practically self-taught, and largely through the medium of experiments, he realized the value of the laboratory method of instruction, and in spite of conservative opposition he set to work to bring about its adoption. He was allowed at first the use of one basement room for his purposes, but was compelled to pay all or nearly all of the laboratory expenses out of his own pocket; for the college funds could not be wasted on strange innovations, and the recitation method still reigned supreme. Professor Cooke, however, understood how to be patient and persistent at the same time. Year by year his courses of study were extended, by slow degrees his resources increased, and in 1858 Boylston Hall, the present laboratory building, was completed. At first, part of the building only was assigned to chemistry, now all of it is devoted to the teaching of that science. It is truly a monument to Professor Cooke, whose energy and persistence caused it to be erected, and to whom more than to any other one man the full recognition of the laboratory method in American

colleges is due. The initiative was taken by the scientific schools, but the colleges were compelled to follow, and today even the high schools, the feeders of the colleges, have their chemical laboratories, in which elementary practice and qualitative analysis are taught. Chemistry is now seen to be one of the best disciplinary studies, and it fails in educational value only when the teaching of it is entrusted to improperly trained pedagogues of the obsolete text-book school. The teacher who is a slave of text-books is as bad as no teacher at all. To teach chemistry one must think chemistry; a mere memory of facts is not a sufficient qualification.

Leaving out of consideration the names of many American chemists who published important researches during this period of our history, for personal details would not be in place here, we come down to the date of the civil war, which marks an epoch in more senses than one. In science as well as in politics, the war divides American history into two periods—the one a period of preparation and slow growth, the other a period of swift advances and fruition. Through the war the nation had received a sharp stimulus, and the reëstablishment of peace was followed by wonderful progress in many directions. Population and wealth increased with great rapidity, and in due time that wealth began to flow into educational channels. The nation itself embarked in many new enterprises; these demanded the aid of science, and so the latter received encouragements which its students had hardly dreamed of before. Even during the war the land-grant college bill was passed by Congress, and soon every State was provided with new facilities for scientific instruction, and the demand for trained teachers was greatly increased. The foundation of Cornell University, which opened its doors to students in 1868, was one of the consequences of this bill. In 1864 the School of Mines of Columbia College began its work; in 1865 the Massachusetts Institute of Technology was started; and these were followed by the Polytechnic School at Worcester in 1868, and the Stevens Institute at Hoboken in 1870. Even the older

schools of science developed more rapidly, and in the Lawrence Scientific School particularly the research method of instruction was pushed into great prominence by Wolcott Gibbs. Hitherto our professors of chemistry had been commonly content with teaching what was already known, but under Gibbs the student was taught to think and to discover. Training in the art of solving unsolved problems became a part of the school curriculum. This phase of chemical education was brought into still greater prominence some years later in the laboratory of the Johns Hopkins University, and now it is well-nigh universal. Original research, once an occasional feature of American college work, is now emphasized in all of our better universities, and the student's thesis outweighs his examination in importance. At first, as was but natural, our educational system was modeled after that of England, with Oxford and Cambridge as the shining examples to follow. Here, as there, the passing of examinations was the one supreme test of scholarship; but the growth of science in Germany attracted our better students thither, and they returned full of the modern doctrines. The German graft upon our English stock has made our universities what they are today; and now the man who can increase knowledge is more highly esteemed than him who merely knows. The knowledge which is fruitful outranks the sterile culture whose end is in itself. In all departments of learning, education has become more vital, more of a living force; and in this great movement forward the chemist has been a leader and a pioneer.

For many, many years the chemists of America were unorganized, a thousand scattered units, each doing what he could as an individual, but with no bond of union other than that of a common interest. Here and there chemical societies were founded, to last for a year or two and then perish for lack of proper support. They were local experiments, nothing more, and no list of them could be made. In the more general societies, like the American Academy in Boston and the Academy of Natural Sciences in Philadelphia, the chem-

ists had a part, but it was one of minor importance, an item among many.

In the American Association for the Advancement of Science there were some chemists who attended the meetings from time to time and occasionally presented papers. They were overshadowed, however, by the more active representatives of other sciences, and their share in the proceedings was rarely conspicuous. The Association was divided at the time of which I speak into two sections, A and B, and in the first of these chemistry, physics, mathematics, and astronomy were crowded together, with chemistry the least prominent of all.

In 1873 the Association met at Portland, and a handful of chemists, most of them young and unknown, but enthusiastic, were present. The time was ripe for a step forward, and that step, a very short one, was taken. The Association was requested to allow the formation of a subsection of chemistry; a year later, at Hartford, the request was granted, and the subsection began its career.

Some two weeks before the meeting at Hartford, on August 1, 1874, about seventy-five chemists met at Northumberland, in Pennsylvania, to celebrate at the grave of Priestley the centennial of the discovery of oxygen. It was now proposed to organize an American Chemical Society, modeled after the already flourishing societies of London, Paris, and Berlin, but action was deferred in order that the new experiment in the American Association might have a fair trial, and that the danger of undue competition, with its attendant division of forces, might be avoided. The new subsection received general support; it grew and flourished, and when, in 1881, the American Association was reorganized it became the full Section C of the present body. Today the chemical section is one of the strongest and most vigorous in the Association; with a large and faithful membership, which has been built up in great measure by the efforts of the men who started it twenty-three years ago.

In 1876 the project for an American Chemical Society was revived, and an organization bearing that name was estab-

lished in New York. It obtained a fair membership and published a journal, but as all the meetings were held in one city, it did not command the support of the country at large, and it became essentially a local body in spite of its claims to national scope. It was national in theory, and also in purpose, but it failed to receive general recognition, and it exerted no widespread influence until after sixteen years of existence it became a potent factor in the development of a larger enterprise.

In 1884 the Chemical Society of Washington was formed. This was professedly local in its character, and so too were several other bodies of chemists which were organized within a year or two of this time. There was no concentration of effort among the chemists of America except in the American Association, and that unfortunately met but once a year. There were nuclei enough, however, for crystallization to begin, and in 1888 another step was taken. The Chemical Section of the American Association appointed a committee to confer with like committees from other societies and to report upon the question of a national organization. Conference after conference was held, report after report was presented; there was opposition, of course, from various quarters and indifference to be overcome; there were conflicts of interest and the inevitable rivalries. But the movement was started; it was finally indorsed in due form by the old Chemical Section, and in time success was won. In 1891 and 1892 a plan was agreed upon and the present American Chemical Society was established.

The two principal factors in the problem, apart from the American Association, were the American Chemical Society in New York and the Chemical Society of Washington. The former had the name and a charter, and, with some reason, claimed to occupy the field. The other made no claims, but would not concede primacy to the first. Professional interests and good feeling, however, carried the day; there were concessions from all sides, and the following plan was adopted: The existing name and charter were accepted. The New

York body became a local section of the reorganized society, and the Washington organization did the same. The old journal of the society was consolidated with the flourishing "Journal of Analytical and Applied Chemistry," with the editor of the latter, Professor Hart, in charge. Other local sections were provided for, and it was agreed that the society should hold two general meetings a year—one in winter, the other in coöperation with the American Association. Thus all interests were reconciled, and the scattered forces of the chemists began to converge toward a single point. A strong society was created with a good monthly journal, and today it numbers over a thousand members, with nine local sections in various parts of the country carrying on continuous work. Hereafter the summer meeting will be held jointly with that of Section C in the American Association, making both bodies stronger and more efficient; all opposition has been overcome, the membership of the society is rapidly growing, and the future seems bright. The example which has been set by the chemists may be a good one for others to follow. "In union there is strength." In New York there is also a section of the British "Society for Chemical Industry;" and in addition to the journal already mentioned there is the well established "American Chemical Journal," managed by Professor Remsen at Baltimore, and a new periodical devoted to physical chemistry, which has just been started by Professors Trevor and Bancroft at Cornell University. Our chemists are now well provided with means for publication, and there seems to be no dearth of material with which to fill the pages of the three separate journals. The "American Journal of Science," the "proceedings" of some local academies, and the foreign chemical periodicals also receive a share of our output. The facilities for publication seem to increase no faster than the activity of the American chemists.

On the purely scientific side the Government of the United States has as yet done little for the advancement of chemical research; but indirectly, for economic reasons, it has done

much, especially since 1876; so, too, have the governments of various States and cities, especially with regard to the analysis of fertilizers and in the direction of sanitary chemistry. Some investigations concerning the water supply of cities have been carried out by local boards of health, and among these the researches instituted by the Massachusetts board have been of the highest scientific quality. No better work of its kind has been done anywhere, and its results, intended for local benefit, are of far more than local value. On the part of the General Government the patronage of chemistry has covered a wide range, and many bureaus have been provided with laboratories. In the Department of Agriculture a considerable force of chemists has long been employed, dealing with questions of the most varied character. The United States Geological Survey maintains another important laboratory, and still others are connected with the Bureau of Internal Revenue, the Mint, the Army, and the Navy. In the torpedo station at Newport investigations are carried out relative to explosives, and at the custom-house in New York a number of chemists are engaged in the valuation of imported articles with reference to the assessment of duties. In short, the Government calls upon the chemist for aid in many directions, and the appreciation of his usefulness increases year by year. In all this work, however, chemistry is rated as a convenience only and valued for what it can give. Its advancement as a science is not considered, and such growth as it gains through governmental encouragement is purely incidental. Good researches of a strictly scientific character, real enlargements of scientific knowledge, have come from laboratories maintained by the Government; but they represent the rare leisure of the investigator and not the essential object of his work. He is sometimes permitted to investigate for the sake of chemistry alone, but such labor is extraofficial and forms no part of his regular duties. The chemist is compelled to serve other interests—other sciences, it may be—and only the time which they fail to demand is his own. Considering the enormous impor-

tance of chemical research to all the greater industries of the world, it should receive fuller recognition by the National Government and be encouraged most liberally.*

I have already referred to the land-grant college act of 1862, under which so many agricultural and technical schools came into existence. In 1887 Congress passed another act, intimately related to the former, by which the States and Territories were each granted the annual sum of fifteen thousand dollars for the maintenance of agricultural experiment stations. These stations, some of which have other resources also, are actively at work, and they receive some coördination under a bureau of the Federal Department of Agriculture. Chemistry receives a part of their attention, and in 1894 one hundred and twenty-four chemists were employed in them. These chemists and those connected with the Washington laboratory are bound together in the Association of Official Agricultural Chemists, which meets annually. A prime object of that association is the improvement, definition, and standardizing of analytical methods, and along this line it has done admirable work. The data obtained in the different experiment stations are thus rendered strictly comparable, and a higher degree of accuracy is reached than would have been attained under conditions of absolute individualism. The association fills a distinct place of its own, and is in no sense a rival of the American Chemical Society. Indeed, the members of the official body are nearly all members of the other.

In the industrial field, as well as in the domain of pure science, the chemists of the United States have made rapid advances during the past thirty years. In manufacturing chemistry the growth has been only moderate—at least in comparison with the growth of other industries—but still it

* For a fuller discussion of this part of the field I may refer to my own address upon "The relations of the Government to Chemistry," published in the Bulletin of the Chemical Society of Washington, No. 1, 1886. In that paper the chemical work of the Government is described with considerable detail.

is evident. We still import heavily, and depend upon Europe for many chemical products which ought to be manufactured here. In some special lines our goods are among the best; in others we are wofully backward. To some extent our tariff and revenue legislation has had a bad effect upon our chemical manufactures (as, for example, in increasing the cost of alcohol), and certain defects in our methods of scientific teaching have also been to blame. To this subject I shall recur presently. In metallurgical processes the United States can hold its own, however, and especially in those which involve the application of electricity. The electrical furnace, for instance, as it is used in the manufacture of aluminum, is distinctly an American invention, and the electrolytic refining of copper is carried out in this country on a scale unknown elsewhere.

If we consider the subject of applied chemistry at all broadly, we shall at once see that it has several distinct aims—such as the discovery of new products, the improvement of processes, and the utilization of waste materials. It seeks also to increase the accuracy of methods, to make industrial enterprises more precise, and therefore more certainly fruitful; in short, to replace empiricism by science. It is, perhaps, in this direction that applied chemistry has made its most notable advances in America, and that within comparatively recent years. Three decades ago even our greatest manufacturing establishments employed chemists only in a sporadic fashion, sending occasional jobs to private laboratories, and then only after counting the cost most parsimoniously. Except in a few dye-houses and calico printeries, the chemist was not fully appreciated; great losses were often sustained for lack of the services which he could have rendered, and the cost of goods was therefore higher than was necessary. By degrees, however, a change was brought about. One effect of industrial competition was to narrow margins and to render greater accuracy of manipulation imperative, and so the chemist was brought upon the scene. Today it is almost the universal custom among manufacturers to main-

tain chemical laboratories in connection with their works, and this is especially true with regard to metallurgical establishments, oil refineries, soap, candle, and glass works, in the making of paints, varnishes, and chemicals, and so on in many directions. Even the great firms whose industries are connected with the Chicago stock-yards, with their artificial refrigeration and their manufacture of lard, lard and butter substitutes, meat extracts, pepsin, and fertilizers, all employ skilled chemists and provide well-equipped laboratories. In the making of steel and iron the processes are followed by analyses from start to finish, from ore, fuel, and flux to the completed billets; and the chemists who are thus occupied have gained marvelous dexterity. The analytical methods have been reduced to great precision, and are extraordinary as regards speed, work which once required a day to perform being now executed in less than twenty minutes. Exact measurement has replaced rule of thumb, certainty has supplanted probability, industry has become less wasteful and surer of a fair return, and to all this the chemist has been a chief contributor. Without his aid the manufactures of the world could never have been developed to their present magnitude and efficiency. His influence reaches even beyond the furnace or the factory and touches the greatest economic questions. Take, for example, the financial agitation through which our country has so recently passed, with its discussion of monetary ratios. Chemical processes have profoundly modified the metallurgy of gold and silver, cheapening the production of both metals and changing the commercial ratio of their values. Can the bimetallic question be intelligently investigated with the chemical factor left out? Furthermore, chemistry has created new industries in which both gold and silver are employed, and so, affecting both supply and demand, touches their ratios still more deeply. When politics becomes true to its definition, when it is really "the science and art of government," then we may expect politicians to consider questions like these and to study the evidence which chemistry has to offer.

One other phase of applied chemistry, chiefly developed in this country, remains to be mentioned. In 1875 the Pennsylvania railroad opened a laboratory at Altoona, in charge of Dr. C. B. Dudley; and eight or nine other great railroads have since followed its lead. In these railroad laboratories, which employ many men, all sorts of supplies are tested, and large contracts for purchases depend upon the results of analysis. Among the articles regularly examined, preliminary to buying, are iron, steel, various alloys, paints, varnishes, soaps, wood preservatives, disinfectants, etc. On the Pennsylvania system alone the purchases controlled by these tests amount to from two to three millions of dollars annually, and the saving to the company is undoubtedly very great. In many cases other purchasers adopt the specifications of the railroad, and base their contracts upon the same standards, the analyses to be made in the same way. Adulteration is thus discouraged and prevented, and the moral effect upon the seller, who must be honest, is most salutary. When detection is certain, the temptation to commit fraud vanishes. To the improvement of analytical methods the railroad laboratories have contributed materially, so that their work has true scientific significance as well as practical value.

Now, although we may properly take pleasure in the advances which American chemists have made, we have no right as yet to be fully satisfied. We have done much, but others have done more; and until we stand in the front rank we should not relax our efforts. The competition of research is fully as keen as the competition of trade, and even if we may win the lead we must work hard to keep it. In spite of all that I have said of its growth, industrial chemistry in the United States is still in its infancy, and comparison with other countries is in some respects wholesomely humiliating. England and France have built up chemical industries vastly greater than ours, and in certain directions Germany leads them both. Moreover, the German industries and the trade depending upon them are increasing at a marvelous rate, and in England the chemists at least have

taken serious alarm at the growing competition. Branches of manufacturing which were once almost wholly English are now mainly German; discoveries which were made in England have been developed in Germany; and now the British economists are seeking for the reason.

To the chemist the reason is plain, and is to be found by a study of two systems of education. The English universities and schools have clung to obsolete methods, and have attached great importance to examinations and the winning of honors. To the honor men positions and preferment are open; but the honors are awarded in the wrong way. In Germany, on the other hand, the pathway to success lies through research, honors are given to the men who have increased knowledge, and the effect of this policy is felt by every manufacturer upon German soil. Take, for example, the great chemical works at Elberfeld, in which about one hundred scientific chemists are employed, in addition to a great force of laborers. Every one of these chemists received a training in research, every one is expected to make discoveries, and the results of their investigations are immediately applied in the manufacture of new preparations and the improvement of processes. The German employer does not ask the chemist to do for him what he can do already, but rather to supply the greater forces by which he can rise above his competitors and command the custom of the world. To that policy we have not yet fully risen in America; our technical schools have thought too much of routine drill and discipline, and until we profit by the example of Germany more thoroughly than we have done, we cannot hope to rival her in chemical industries. Our practical men value science for what it can do directly in their interest, and rarely look deeper into the possibilities of abstract investigation. In reality, pure science and applied science are one at the root; the first renders the second possible, and the latter furnishes incentives for the first. Where science is most encouraged for its own sake, there its applications are most speedily realized. This is a lesson which America has yet to learn, at least to the point of full and complete appreciation.

What, now, have we done, and what should we do? We have made a great beginning; we have built up good laboratories, backed by richly endowed institutions of learning; millions of dollars have gone into the teaching of chemistry, and the stream of research flows on with ever-increasing volume. American investigations and investigators are known throughout the civilized world; their creditable standing is fully recognized; our analysts are among the best, and yet—and yet—something is wanting. A great mass of good work has been done, beyond question; but no epoch-making generalization, fundamental to chemistry, has originated in the United States, nor has any brilliant discovery of the first magnitude been made here. The researches of American chemists have been of high quality, but not yet of the highest; there is solidity, thoroughness, originality; but with all that we cannot be satisfied. The field is not exhausted; there are great laws and principles still to be discovered; the statical conceptions of today are to be merged in wider dynamical theories; for every student there are opportunities now waiting. Shall we do our share of the great work of the future, or shall it be left to others? Shall we follow as gleaners, or lead as pioneers? He who has faith in his own country can answer these questions only in one way.

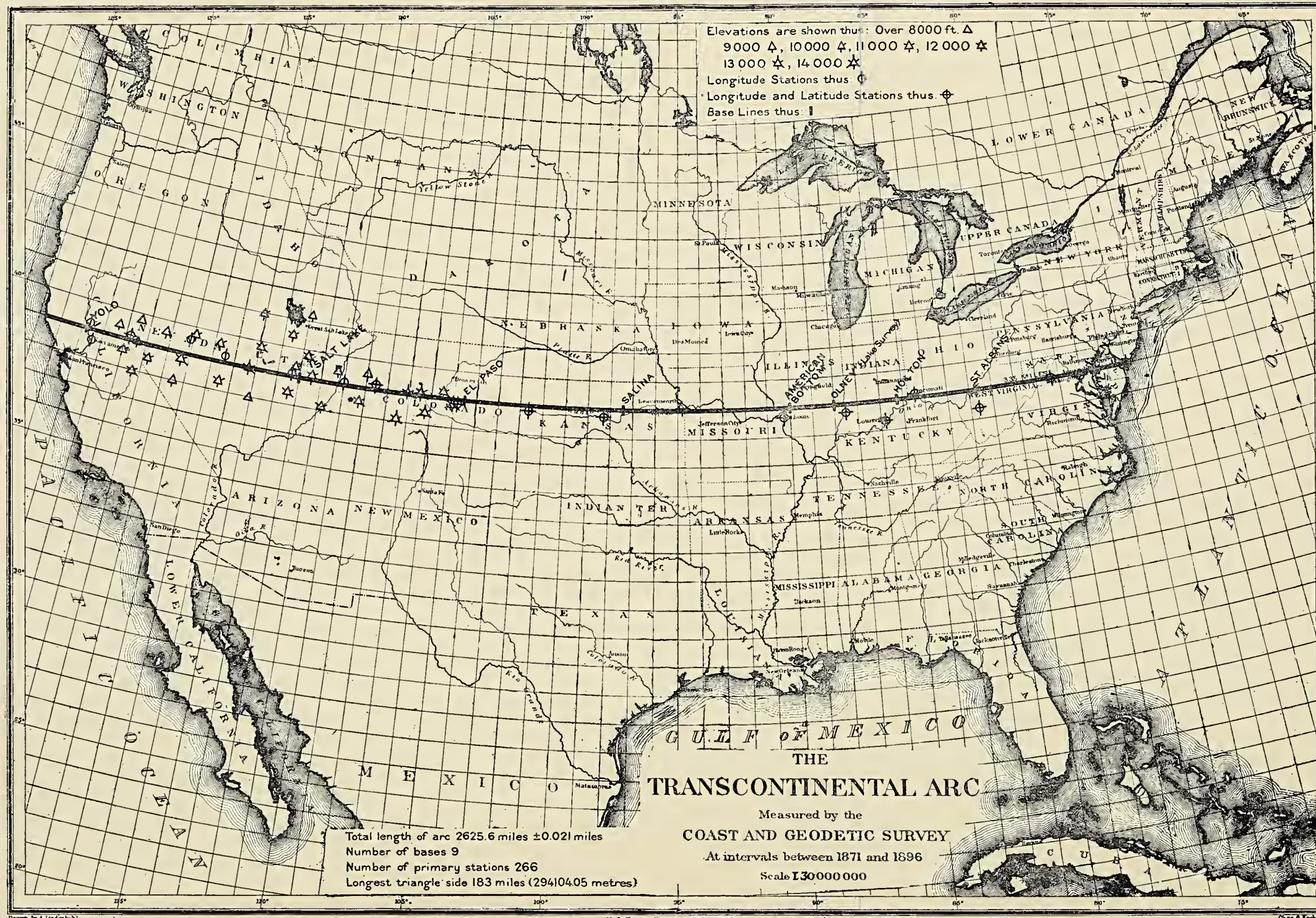
At present American chemists labor under some disadvantages which have not been fully outgrown. Research with most of them is at best encouraged, but not expected as an important professional duty. The teacher must first teach, and in too many cases the routine of instruction takes all his strength and time. The resources available for education have been scattered by sectarian rivalry; several schools are planted where only one is necessary, and the teachers, duplicating one another's work and furnished with slender means, cannot specialize. Two chemists dividing the work of one institution can do more than four who labor separately. The field is too large for one man to cover alone, and yet most of our men are expected to do it. This evil, however, is growing less and less, and in time it may cease to operate. With the

increase of true post-graduate instruction the work of American chemists will improve, for in that part of the educational domain research is an essential feature. Give our men the best opportunities, the best environment, and they will do their share of the best work.

In one direction, perhaps, the possibility of advancement is greatest, and that is in the institution of laboratories for research. At present the labor of investigation is unorganized, unsystematic—a little here, a little there, but without coördination—and consequently our knowledge is after all a thing of shreds and patches. In making this statement I do not exaggerate. Take any class of scientific data, examine any series of chemical compounds, and note the gaps which exist in it. A chemist in Berlin has studied one of the compounds, another in Paris has prepared a second, many bits of information have been gathered by many individuals, and so knowledge slowly accumulates. The organization of research is to be one of the great works of the future, when discovery shall become a profession, and groups of students shall coöperate toward the attainment of clearly specified ends. To some extent this work has already been done for astronomy, and more than one observatory could exemplify what I mean. In a fully manned and equipped observatory great investigations, too large for one astronomer to handle alone, can be carried out systematically; and this is actually done. In mapping the heavens, even, several observatories can combine their forces, each one covering a definite part of the field; but in chemistry no policy of this kind has yet been possible. The extension of the observatory method to other departments of science is the advance for which I plead.

Suppose, now, we had a great laboratory, fitted up for chemical and physical work together, well endowed and well manned, what might we not expect from it? Great problems could be taken up in the most thorough and orderly fashion, methods of work might be standardized, and groups of physical constants determined. The results would aid and

stimulate individual students everywhere, and applied science, too, would receive its share of the benefit. There is today a growing commercial demand for accurately determined constants, and no institution in which the demand may be adequately supplied. At Charlottenburg, in Germany, there is a beginning; in London the munificence of Ludwig Mond has made possible a similar start; but nowhere is such a plan as I propose in full and perfect operation. The United States has great observatories, fine museums of natural history, and flourishing universities. Why should it not have institutions for physics and chemistry also? These sciences touch many industries at many points; their applications have created wealth beyond all possibility of computation; now let that wealth do something for them in return. Half the sum that the nation spends in building one battle-ship would erect, equip, and endow a laboratory more complete than any now existing, whose influence would be felt throughout all civilized lands and endure as long as humanity. In this the United States might take the lead and set a great example to all other nations. The United States has long been a follower in science; may she soon take a higher place as teacher.


Elevations are shown thus: Over 8000 ft.
9000, 10000, 11000, 12000
13000, 14000
Longitude Stations thus:
Longitude and Latitude Stations thus.
Base Lines thus:
THE
TRANSCONTINENTAL ARC
Measured by the
COAST AND GEODETIC SURVEY
At intervals between 1871 and 1896
Scale 1:3000000
Total length of arc 2625.6 miles ±0.021 miles
Number of bases 9
Number of primary stations 266
Longest triangle side 183 miles (294104.05 metres)
GULF of MEXICO
PACIFIC OCEAN
ATLANTIC OCEAN
MEXICO
YOLO
SALT LAKE
EL PASO
SALINA
AMERICAN BOTTOM
OLNEY
HOLTON
ST. ALBANS
Drawn by A. Lindenkohl
U. S. Coast Survey Office 1866.

THE TRANSCONTINENTAL ARC.

BY

Erasmus Darwin Preston.

[Read before the Society February 20, 1897.]

Introductory.

The United States Coast and Geodetic Survey is one of the scientific institutions of the Government that has kept pace with the expansion and development of our country. Conceived by Thomas Jefferson one hundred years ago, established by Congress in 1807, and reorganized by President Tyler in 1843, it has continually adapted itself to the growing needs of commerce and defense. Without departing from the lines of policy originally laid down, its scope has broadened from time to time, in response to changing conditions, and its details have been worked out to satisfy the demands of the day.

Taking as its fundamental idea the delineation of land and sea in the vicinity of tide-water, the department has not failed to follow coördinate lines of research when such work was incident to and necessary for the successful prosecution of its legitimate task. The spirit of the Survey has been one of progress. Guided by the inventive minds of Hassler, Bache, and Hilgard, the service early adopted radical modes of treatment. The application of the zenith telescope to latitude, the electric telegraph to longitude, the polyconic projection to charts, and the plane-table to topography revealed new possibilities in the realm of geodesy. To these four agencies may be ascribed the rapidity, accuracy, and economy which have characterized the production of results.

*Published by permission of the Superintendent of the United States Coast and Geodetic Survey.

We have only to compare the methods of today with those hitherto employed to realize the phenomenal advance in the practice of surveying. The precision attainable in the astronomical determination of a point on the earth's surface has certainly increased fivefold in the last fifty years. It is not to be expected that the fathers of our Republic should foresee all of the necessities growing out of the proposed "survey of the coast." Nothing in the original act of Congress gives authority for the observation of terrestrial magnetism, unless such authority is implied in the words "together with such other matters as may be deemed proper;" yet no civilized nation today would undertake a trigonometrical survey without determining the variation of the magnetic needle. There would seem to be at first sight no intimate connection between the measurements of the force of gravity and a trigonometrical survey of a country, nor between the temperature and density of the Gulf of Mexico and the hydrographic conditions along our eastern coast; yet both the law of falling bodies and the subocean currents are now regarded as a legitimate and necessary study in connection with a survey of the national domain.

Every trigonometrical survey of great extent has been confronted with the question, "What is the size and shape of the earth?" and every nation within the measure of its ability and opportunity has added something to our knowledge on the subject. It is evident that those countries whose domain is extended in the direction of the meridian possess unusual facilities for contributing data to the solution of the problem. England, France, and Russia have thus far been the most active governments in this respect, and have together measured nearly ninety degrees of latitude. Less than ten degrees have been measured in the southern hemisphere. The United States have measured an oblique arc of 22 degrees, several smaller ones running north and south, and have just completed the longest parallel arc ever undertaken by a single government. Not content with this, work has already begun on the ninety-eighth meridian, which is

to start from Manitoba, in the British possessions, and end at Neuvo Leon, in northern Mexico. We have here 23 degrees, making the line practically as long as the Russian and Indian arcs, and 10 degrees more may be added by our sister Republic on the south.

Reduced to its simplest expression, the method of getting the size of the earth from the measurement of arcs is nothing more than the determination of the curvature of the meridian. When the curvature is known at two points of the quadrant the entire ellipse may be traced and the shape of the earth is established. It requires no knowledge of conic sections to understand that arcs measured in middle latitudes have very little effect on the determination of the earth's figure, and, on the other hand, that the most suitable arcs are those where the curvature is greatest and least—that is, at the equator and at the pole. Although millions of dollars have been spent directly and indirectly on the solution of this problem, we have not yet reached a final result. The statement as to cost just made, includes of course the outlay of all nations on the work, and it may be added that incidental aid toward the result is furnished by surveys that were first undertaken for a different purpose. Just here the question naturally arises, "Does a figure of the earth deduced from European measurements fit the United States?" or, in other words, "Does the western hemisphere have the same curvature as the eastern?" The reply, as far as our measures enable us to judge, is that it has. It has just been stated that we have not yet a final figure, but the old spheroid of Bessel (1841) has been superseded in the Coast and Geodetic Survey by Clarke's determination (1866). The last-named figure is both larger and flatter than the first. In fact, a line across the United States from Cape May to San Francisco is longer by one-third of a mile when measured on the spheroid last adopted. A complete trigonometric survey implies accurate geographical positions. This demands astronomical observations to the last degree of precision, and so it turns out that our survey of the coast requires incidentally

a thorough knowledge of the variations of latitude, the aberration of light, and the mean density of the earth.

Congress has recognized this, and money has been appropriated for the purpose. An observer was sent to Honolulu, and there, coöperating with astronomers in San Francisco, Washington, and Berlin, the change of latitude was studied during an entire year. The Honolulu and San Francisco results were discussed by the formation and solution of over 9,000 conditional equations, nearly 7,000 of which appeared in one group and directly determined a single unknown quantity—the aberration constant.

One might naturally inquire, What has the density of the earth to do with the measurement of angles on its surface? The connection between them is best shown by an example: In a mountainous region a line was measured whose length did not agree with the known difference of latitude between the extreme points. To explain this discrepancy it was necessary to assume that the plumb-line was drawn out of its normal position, or that there was a disturbance in virtue of which the observed astronomical latitudes were not the true ones. The force of gravity was measured on the intervening mountain, which showed a density for the underlying matter just sufficient to account for the attraction of the plumb-bob in obedience to the laws of gravitation. This interesting piece of work was done in the Hawaiian islands, where it was discovered that the pendulum on being carried to the summit of the mountain lost 28 oscillations per day instead of 41, as required by the law of the inverse square of the distance. The acceleration of 13 oscillations per day indicates a density of the mountain sufficient to deflect the vertical at its base by nearly half a minute of arc, which was precisely the observed discrepancy.

The Transcontinental Arc.

On the 3d of March, 1871, Congress made an appropriation "for extending the triangulation of the Coast Survey so as to form a geodetic connection between the Atlantic and Pacific coasts of the United States."

The ultimate necessity of such a step had been apparent for some time. The intricate and ever-growing network of trigonometric lines along the coast and down the Appalachian chain demanded a greater extension in order to fully subserve its original purpose. The secondary and tertiary work along the low coast line of the south required control. Eighteen thousand miles of triangulation exist from the mouth of the Chesapeake to Mobile bay. The various conditions under which it was executed, as well as the different methods of measurement, made some check operation imperative; for we must remember that around the shores of Florida water signals are employed, and direct measurements along the beach are resorted to in order that heavy cutting through the mangroves may be avoided; so that a primary triangulation in a direct line from Washington to Mobile becomes a necessity to test the work done along the Atlantic and Gulf coasts.

In the same sense that a line of control is necessary for the work along the eastern and southern shores, there exists a still greater obligation to bind into one harmonious whole the geodetic operations on the Atlantic and Pacific coasts. It was to supply this link that the "transcontinental arc" was begun, and we now have the satisfaction of knowing that it is practically completed, and that our country can point with pride to the largest arc of longitude ever measured by any single government.

The author disclaims all pretension toward having contributed to any very great extent to the accomplishment of this work. It is, however, not possible, even were it desirable, to name all the persons to whom credit is due. Among the many officers whose names appear with more or less frequency two occupy an unique position. One has carried the triangulation over the Rocky mountains, and for twenty years has practically made all his observations above the clouds. The other has had charge of the laborious calculations, and for a quarter of a century has given the subject special attention. The former is Mr. William Eimbeck, to

whose perseverance is due the successful termination of the triangulation from the Sierra Nevada to the Mississippi valley, and the latter is Mr. C. A. Schott, to whose untiring industry we owe the discussion of the results.

From Cape May light-house, in New Jersey, to Point Arena light, in California, the distance is 2,625.6 miles. These points are within a very few miles on the same parallel of latitude, which, by the way, is that particular parallel on which the center of population of the United States seems to be tracing its course.

In this grand network there are 266 primary stations, involving the measurement of many thousand angles; and if we consider the subsidiary points determined, it can truthfully be said that the number of localities precisely established in latitude and longitude by this great chain exceeds that of the stars visible to the naked eye.

There are several unique features. The arc consists exclusively of quadrilaterals or figures equally as strong. No single triangle has ever been permitted to carry the work forward, and where the diagonals of quadrilaterals were inconvenient or impracticable, pentagons or hexagons were substituted. Four stations are above 14,000 feet elevation and twenty are beyond 10,000 feet. Let any one imagine the difficulties of making observations at an elevation of $2\frac{3}{4}$ miles. Consider that at this altitude the barometer stands at $18\frac{1}{2}$ inches; that there is perpetual ice and snow; that water boils at 189 degrees, and that, there being only about one-half the usual amount of air, every one is more or less affected by mountain sickness.

At one time it fell to my lot to occupy a station in the tropics at 14,000 feet, and I can certify that the experience is not altogether pleasant. Snow and ice in July, and in the tropics, and on a party coming but a few hours previous from a torrid atmosphere, where the system is debilitated by long months of sunshine, is to most persons the severest test of endurance.

On the transcontinental arc 9 bases have been measured.

They are mostly modern, but one of them, the "Kent Island," in Maryland, was used as early as 1844. It is not to be expected that the degree of accuracy now required was possible fifty years ago, and so we find this base with a degree of precision only about half that now attainable: $\frac{1}{228000}$ of its length (5.4 miles), or 1.5 inches, may be given as the probable error of the assumed length. I shall later speak of the relative accuracy of the different bases employed on this chain, but before passing to that it is desirable to examine the conditions that govern the number and location of base-lines in any system of triangulation. It may be assumed as a guiding principle, that check-lines should be measured just so often and at just such distances as will be necessary to control the triangulation and keep it within the degree of accuracy sought.

In the main triangulation east of the Mississippi river we may assume $\frac{1}{63000}$th part as the limit of error. From St. Louis to Colorado Springs $\frac{1}{100000}$ is easily attained, while from the last-named point to the Pacific the error to be feared is only $\frac{1}{200000}$th part.

If we then take the middle figure as the index of accuracy which it is proposed to attain, the line of reasoning would be as follows:

From a great number of observations the mean error of a measured angle is ascertained. From the actual angles employed and the length of the base-line the reciprocal of the weight of any assumed side is found. The square root of this last quantity multiplied by the first will give the mean error of the side in question, and the probable error will be two-thirds of this. Comparing the result with the length of the side, we get the limit of accuracy for the distance traversed. Dividing by $\sqrt{2}$ gives the effect of two base-lines, and hence we have the total error to be expected in the junction line midway between the bases. It is understood that the accuracy of any given side is influenced both by the base and angle measurement; but while the error from the former is a function of the length of the side and transmits itself in-

dependently, the error from the angular measures varies with the particular values assumed by the trigonometrical functions in the intervening triangles. To specify actual figures obtained in practice it may be said that the mean error of a measured angle is 1″.07, and that the probable error of an average side of 26,600 meters is $0^{m}.335$, giving an error of $\frac{1}{112000}$ part in the junction line between the two bases 200 miles apart.

The probable error of a side increases as the square root of the number of triangles, and we find the following relations:

At 100 miles from the base.........probable error.. $\frac{1}{112000}$
At 120 miles from the base.........probable error.. $\frac{1}{100500}$
At 150 miles from the base.........probable error.. $\frac{1}{91800}$

so that we may assume 240 miles as the limit of the distance between bases where an accuracy of $\frac{1}{100000}$ part is desired. When one base is brought to another by calculation, there will in general be four discordant elements, requiring four conditional equations for their complete reconciliation; these are length, azimuth, latitude, and longitude.

As the base lines are susceptible of measurement to a far higher degree of precision than can be maintained in our best schemes of triangulation, so also is the triangulation capable of fixing points on the earth's surface more accurately than astronomical observations.

On the transcontinental arc we have about 80 astronomical latitudes, 40 telegraph longitudes, of which more than 20 are primary, and 60 azimuths. Many of these stations are above 10,000 feet elevation—a few are above 14,000 feet—and all have been determined with especial reference to the demands of coördinate parts of the work in that particular locality. Parenthetically it is proper to speak of the precision of the arc, taken as a whole, and of its expense. Taking into account all the sources of inaccuracy, it may be assumed that the distance from the Atlantic to the Pacific along the thirty-ninth parallel of latitude is known within about 100 feet,

which shows an error less than $\frac{1}{1000000}$ part. This line is shorter on Bessel's spheroid than on Clarke's by 2,000 feet. Our uncertainty of 100 feet can therefore not affect the decision as to the proper figure to be adopted for the United States.

A quarter of a century of hard work, sometimes under the most adverse circumstances, and an expense of half a million dollars is the price paid for the above result. In considering this outlay of money we must bear in mind that the occupation of one of the mountain stations alone cost $10,000, and required an entire season for its completion. Of the nine bases that have been measured on the arc, the most expensive one was the Yolo, 11 miles long, and it cost in round numbers $10,000. The two measures of the Salina base, with a length of four miles, cost $2,610. The longest line observed was from Uncompahgre, with an elevation of 14,300 feet, to Mount Ellen, 11,300 feet high, giving the unprecedented single sight through a distance of 183 miles (294,104.05 meters). Work of this magnitude has never been attempted by any nation hitherto. The nearest approach to it is by the French and Spaniards, who, in 1879, threw a quadrilateral across the Mediterranean from Spain to Algiers, but their highest station—the highest mountain in Spain—falls 3,000 feet short of Uncompahgre, and their longest diagonal is 15 miles shorter than our own. It is quite true that the English in India have seen the summits of the Himalayas at a distance of over 200 miles, and have determined their direction, but these peaks have never been occupied and form no integral part of their triangulation; so that the United States can boast of the longest line, the highest station, and the greatest continuous chain of triangles. Unlike some of the projects where Americans strive to attain the "biggest on earth" idea, the transcontinental arc can safely challenge comparison in any of its features with the best examples of similar work. The accuracy of the result and economy of execution are only surpassed by the difficulties of its details and the magnitude of its conception. There are more than twenty lines

over 100 miles in length, each of which has been observed from both directions.

This statement calls to mind some special devices employed on the work. On the western coast a tree was cut off at a distance of 100 feet from the ground and an observing scaffold mounted on the standing shaft. This ingenious method overcame intervening obstacles, and at the same time secured great economy in construction. In Maryland, where the level nature of the ground demands signals of extraordinary height, the plan was adopted of first building the ordinary scaffold 175 feet high and then putting a pole 83 feet long on top of it. This furnished a signal for observation 258 feet from the ground at half the expense necessary for complete tripods. In another instance a pole 120 feet long was erected on a scaffold of equal height. In the Sierra Nevadas heliotropes are brought into use, and the signals from distant stations 100 miles away are visible only as a beam of light shining with the brilliancy of a star of the second magnitude. The great length of line precludes the possibility of recognizing any natural object, and the low clouds cut off the mountain peak itself; yet through the mist and vapor comes the reflected ray of sunlight, and upon this the observer directs his telescope.

The full value of the transcontinental arc is not at first apparent. Not only is it national in its use, but every State through which it passes comes into possession of accurate geographical positions; and not alone that, but every State lying near the thirty-ninth parallel can, at slight expense, fix its own boundaries with an accuracy not inferior to that given by the best government surveys in the world. No less than sixteen States are directly benefited by the triangulation across the continent, and as many more have the possibility of benefit.

With the advance of refined methods and the ability to execute work of a magnitude unknown in earlier days, we are now obliged to carry the computations to a degree of precision commensurate with the newly imposed conditions.

Ten years ago no one would have thought of giving the latitude as a function of the time. Thanks, however, to international work in which the Coast and Geodetic Survey has taken a very creditable part, we are now able to state the law according to which the latitude changes, and all our latitudes are consequently corrected and reduced to what they were at a certain definite epoch. It will no longer suffice to write unconditionally the latitude of Washington. Modern exigency requires that the time be given at which it had this particular value.

So with the correction for height. Before the subject of potential had attracted much attention and before latitudes of precision were observed at great altitudes no one thought of correcting these results for elevation; but Gauss showed, in 1853, that the plumb-line changes its direction as we recede from the earth's surface, and the same fact has been developed from the theory of potential by more recent writers. We must therefore take into account what is called the curvature of the vertical and apply a correction to every latitude that is observed at a considerable distance above the level of the sea.

It is an established fact that the surfaces of two confocal ellipsoids subject to the influences of attraction and rotation are not parallel. It follows from this that the surface of a lake on a mountain top converges toward the surface of the sea. Moreover, it is known that the convergence varies with the latitude, and that the angle is measured approximately by the difference of height for stations situated near the same parallel. The convergence of two corresponding meridians in the two surfaces will be identical with the inclination of the plumb-lines, and we therefore have a value for the deviation of the vertical in passing from the sea-level to greater elevation.

It may be roughly stated that for the transcontinental arc there is a correction of one-twentieth of a second for each 1,000 feet of height, and since many of our stations are above 10,000 feet and some are beyond 14,000, it is evident that

the correction is one of frequent application. It is, moreover, a quantity that cannot be ignored, when we consider that the uncertainty of the latitude results is probably not more than one-tenth part of the influence of elevation on our higher stations.

Considered as a contribution to science, as well as in its map-making usefulness, the transcontinental arc must be studied from several points of view. A simple chain of mathematical figures from the Atlantic to the Pacific will measure the distance and give the basis for a correct delineation of the country; but by stopping at this point we should fall far short of our full duty. In the progress of the work golden opportunities have presented themselves for the development of the coördinate parts of every well-ordered trigonometrical survey, and these occasions have not been allowed to pass by unheeded. Incident to the work in question and growing out of its results has come knowledge of the laws of refraction, the aberration of light, the deflections of the plumb-line, the force of gravity, and the mean density of the earth. Twenty stations have been occupied on the arc for gravity measures, and the results have already been presented to the public. No one can now deny the value or scientific interest in work of this kind, since it has been conclusively shown in Europe that a measurable connection exists between the deflection of the plumb-line and the variations of gravity. On a line from Kolberg to Schnee-Koppe the plumb-line was drawn almost invariably in the direction of an excess of gravity, as revealed by the pendulum, and it has even been laid down as a rule that the variations of gravity can be referred to the attraction of matter of a density of 2.4, a millionth of a meter in the former corresponding to a meter of thickness in the latter.

The pendulum-work may be considered as still in its infancy. Nevertheless both the method of making the observations and the interpretation of the results have passed through several distinct stages. First we had a ball of metal suspended by a fine wire. Then came the reversible

pendulums for the determination of the absolute force of gravity in each particular locality. Later, when it was found to be much more difficult to measure its length than to determine the time of oscillation, observers went back to relative work and adopted the invariable instrument. Then it suddenly appeared that all necessary accuracy could be attained and results produced more rapidly by making the pendulum one-fourth as long, and therefore oscillating in one-half the time. That is where we are at present, and the greater part of the measurements of the force of gravity throughout the world today are made with half-second pendulums. The two principal types of apparatus are those employed by the Austrians and the Americans. Either form will give an accuracy in the period of about double that formerly obtained. A comparatively short experiment will now furnish us with the time of oscillation within one-millionth of a second.

With regard to the treatment of the results, there is still some difference of opinion. A French observer made pendulum experiments in Peru about 150 years ago. Although his instrument was but a piece of lead suspended by a string cut from a native plant, the result obtained has been verified by modern observers in many parts of the world. Having compared the times of oscillation at the sea-level and at the summit of the Andes, he found that the decrease of the force of gravity was not as much as he expected from Newton's law of the inverse square of the distance. The discrepancy was attributed to the downward attraction of the mountain mass between the summit and the sea. An estimate was made of the density of the earth's crust and a mathematical formula was evolved for the reduction of gravity observations to the sea-level. This is the first application of such a correction. Now we come to the point mentioned a moment ago, viz., that the Peruvian work has been confirmed by later observations. Correcting the result for the supposed attraction of the mountain, it was found that the Andes under this supposition were not much heavier than water. Strange as

the result appears to be, all gravity determinations on continental mountains, when corrected in this way, show the matter under the station to be exceedingly light. Then the observers set about finding an explanation, and they hit upon the idea that great caverns must exist under the mountain ranges; but when observations were made on island mountains, the reverse was found to be true—*i. e.*, that islands are generally heavier than one would expect. So, then, we are confronted by these two facts: Continents show a defect of gravity, and islands, at least in the middle of the oceans, an excess of it. The Coast and Geodetic Survey has carried out gravity work at the principal island groups of the Atlantic, on the coast of Africa, in the Pacific ocean, and on the shores of Asia, and the general result has been, as stated, that the force of gravity is apparently least where we would expect it to be greater, and *vice versa.*

It has recently been proposed to omit the correction for continental attraction altogether, because by so doing the results are much more consistent with Clairant's law. It cannot be admitted for a moment that the visible mountain masses exert no accellerating influence on the movement of the pendulum, but since no effect is discernible there must be compensation from some cause, and we are forced to the conclusion that there must be a deficiency of density under the continents.

Let it be put in this way: Every pyramid of matter with its apex at the center and its base at the surface of the earth contains the same mass. This assumption does no violence to preconceived notions. Any contracting sphere will take such a form as will most easily relieve its tangential strains, and if the ocean bed has sunk and by lateral pressure lifted the continent we must admit a diminution of density.

Summing up the situation, then, for the present status of gravitational research, we may say that after many years of trial an apparatus has been found that is satisfactory for the rapid and economic production of results. It only remains to multiply stations. In the theoretical treatment of the data

acquired we have learned much from experience, and future results will throw stronger light on the problems before us. What we want, above all things, is a means of measuring the force of gravity at sea.

One word more in general touching sources of inaccuracy and the agreement of results. In the work around the District of Columbia it became necessary to observe the Capitol dome from both sides and at different times. In the results there appeared a discrepancy so large and of such a peculiar nature as to call forth an investigation. It seemed as though the Goddess of Liberty changed her position from time to time. When the results were carefully examined it was noticed that in the forenoon she was apparently too far to the west and in the afternoon too far to the east. Then it occurred to the investigator that possibly this peculiar movement might in some way be connected with the sun. This was tested by calculating how much the iron dome might be expected to yield by expansion from the influence of the sun's rays, and it was shown that the fair goddess in making her daily bow to the ruler of the solar system moved her head by an amount quite sufficient to explain the discordant observations.

This case is cited not because it is interesting in itself, but for the reason that we have here an example of how simple a cause may be whose effects remain long unexplained. There are many similar instances. Take the gravity measures. Observations with different instruments would not agree until some one noticed that the support of the pendulum was set in motion by the experiment, and that the air was viscous, and therefore adhered to the vibrating body and was drawn along after it. The viscosity correction was then introduced as a feature of gravity work. Recently a large discrepancy was found to exist in the direction of a line; the cause, now apparent, but for some time unsuspected, is lateral refraction, resulting from the proximity of the line of sight to the mountain range; and so we might go on noting instances of the same kind. Results that are systematically

discordant may always be reconciled by carefully gathering facts and seeking the cause.

The supreme test of a result is its verification by independent methods or its agreement with known laws, and in conclusion I shall call attention to a few tests that have been applied to the work in question. The simple operation of closing a triangle is of daily occurrence. In the best work of our arc the accuracy attained is such that the lines of sight are within a fifth of a second of the truth, which amounts to saying that the linear value of the uncertainty is only $\frac{1}{100000}$ of an inch on the limb of the instrument used.

Independent determination of points in latitude and longitude by astronomical observation will be within 10 feet of the astronomical position. In order to fully appreciate this degree of precision, we need only reflect that a change of 10 feet in the position of a latitude instrument on the earth's surface corresponds to a change of height of one end of the level by $\frac{1}{100000}$ part of an inch—that is to say, we would observe the same effect in our bubble by moving the instrument 10 feet as we would by lifting one end of the level the amount stated. This shows that 10 feet on the surface of the earth determined by astronomical means is a very small and almost inappreciable quantity.

The longitude work has an accuracy equal to that just cited, the uncertainty being about $\frac{1}{200}$ of a second of time in primary positions.

The quality of the triangulation is best shown by a comparison of bases. The Fire Island one, nearly 9 miles long, was determined in five different ways through 1,800 miles of triangulation, and the extreme range of the results is only two-tenths of a meter. The value from Kent Island base, 5 miles long and 263 miles away, only differed from that given by the Atlanta base, nearly 6 miles long and 868 miles away, by one centimeter.

Another striking example is found in the agreement of the American bottom base, measured by the Coast and Geodetic Survey, and the Olney base, measured by the United

States engineers. Here is an instance where two organizations, working independently, at different times, with dissimilar instruments, could find no appreciable difference in their results after their bases had been carried 110 miles by triangulation. This is even more remarkable than the celebrated work of the Spaniards on the plains of Madridejos, where the probable error of their base-line is given as approximately $\frac{1}{5000000}$ part. The perfect coincidence, however, of the two bases cited above must be regarded as purely accidental.

A CENTURY OF GEOGRAPHY IN THE UNITED STATES

BY

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Men and women occupied with the small and special details of a large and complex work are not well situated for understanding the scope of the large work to which they contribute. The shop girl in Waterbury who spends her days and years in cutting threads on tiny screws may have very limited knowledge and erroneous opinions about the watch industry. The trained arithmetician who spends his months and years in adjusting triangulation or verifying computations does not thereby acquire valuable opinions as to the scope and conduct of a great national survey. In our day many, if not all, branches of human knowledge and activity are widening. As they widen they are specialized. The student of nature, the practitioner of medicine or law, the artisan, each is prone to contract the size of his field of activity, and to study more profoundly some small part of the large subject. Even the farms grow smaller and are better cultivated than formerly. Such subdivision of the field of study and activity into special and smaller fields has for a century at least progressed steadily, and the world has gained thereby. Many have become profoundly learned or highly skilled in some small subject. You will recall the story of the German professor who near the close of a long

life devoted to the dative case regretted that he had chosen so large a field. "I ought," said he, "to have confined myself to the iota subscript." I will not deny—nay, I am persuaded that the specialization of which I speak is wise, that by it the welfare of the race is promoted. But while this is so, it should ever be borne in mind that specialized knowledge is not a substitute for general knowledge. It is something called for by the increased and increasing sum of human knowledge; but if by it the number of students of larger and unspecialized fields is greatly reduced harm may, indeed must, result.

My purpose, however, is not to call attention to possible perils from undue specialization, for before this audience that is unnecessary. The subject has been discussed and is well understood.

For many years my work has been along geographic lines, and this has led me to select as the theme for this annual address *the Geography of the United States;* not its mathematical geography, nor its physical geography, nor its political geography, nor its commercial geography, any one of which might be treated with more ease than the general subject. And yet a consideration of the whole field and a picture of the general progress made in the geography of the United States since its creation will, it is hoped, prove profitable—more profitable, indeed, if well done, than a more minute examination of a more limited subject. It is not uncommon when a subject of large scope has been chosen to hear the comment, "He has chosen a large subject;" and sometimes we think we see in this an implied opinion that the speaker shows either unwisdom or audacity in such choice. I will not deny that either or both may be true in this case, but will at once invite you to follow me in a most general review of a century's progress in the diffusion of geographic knowledge in and as to the United States.

It is not to the details or agencies by which our knowledge has been acquired that I would draw attention. This has already been done many times. In the stout and repulsive black

volumes that for years have, from the government printing office, been poured out over the country without stint or price—in these are set forth with elaborate minuteness the geographic work done by the United States. The particular fields investigated by boundary surveys, by the Coast Survey, by the General Land Office, by the Lake Survey, by the Pacific Railroad Surveys, by the Wilkes Exploring Expedition, by the Rodgers Exploring Expedition, by the so-called Hayden, Wheeler, and Powell surveys, by the Northern Transcontinental survey, by various State surveys, topographic and geologic, and by the U. S. Geological Survey—all these are duly recorded and published in scores of forbidding black volumes. These volumes record the *increase* in geographic knowledge, but throw little light on its *diffusion.* For *this* we look to the text-books, to public addresses in Congress and out, to newspaper and magazine articles, and to public lectures. These reflect the general knowledge of the community as to geography. This phase of the subject shall be our theme.

It is now one hundred and nine years since thirteen sovereign and independent states, loosely bound together in a confederation, agreed to form a "more perfect union." By a narrow majority and after protracted debate they accepted the terms of an instrument which bound them in an indissoluble union. In April, 1789—one hundred and eight years ago—Washington was inaugurated. That we may clearly note our geographic progress since that event let us picture to ourselves in broad outline the geographic environment of that time.

The total area of the original thirteen states was 830,000 square miles, an area a little larger than Alaska. The population was about 4,000,000, or a little more than that of Greater New York today. Of the whole area only about 30 per cent contained any population, and even within this area the people were gathered for the most part in a narrow fringe along the Atlantic seaboard. The largest city was New York, with a population of 33,000—*i. e.*, it was about as large as the

Yonkers or Youngstown of today. Waterbury, Connecticut, with a population of 29,000, is a little larger than was Philadelphia in 1790. Boston contained a population of 18,000; Charleston, South Carolina, 16,000; Baltimore, 13,000, and Salem, Massachusetts, 8,000. After these only thirteen others, all still smaller, find a place in the first census.

Maine was a province of Massachusetts, with a northeastern boundary undefined and awaiting an international boundary conference for its determination. Most of its territory then was, as some still is, barely explored. To the north, then as now, was a British province; to the west and south, Spanish possessions. This phrase Spanish possessions must here be taken in a Pickwickian sense, for these regions owned by Spain were still almost exclusively possessed by the aborigines.

Traveling was chiefly done on horseback and by stages. The days of railroads and steamboats were in the future. Even the system of canals and national highways, so much exploited in the early decades of the century, was not yet begun.

Of maps of the region there were several, fairly good for their time. None of them, however, were based on surveys. The maps of Thomas Jefferys, geographer to King George during the revolutionary period, are as a whole the best, and fairly representative of the geographic knowledge then existing. While these maps of Jefferys, as well as others, recorded the best geographic information then extant, it does not appear that the information they contained was widely diffused. General ignorance as to geography must have been great. Noah Webster, the lexicographer, writing in 1840, says of the teaching in the schools when he was a boy:

"When I was young, or before the Revolution, the books used were chiefly or wholly Dilworth's spelling books, the Psalter, Testament, and Bible. No geography was studied before the publication of Dr. Morse's small books on that subject, about the year 1786 or 1787. * * * Except the books above mentioned, no book for reading was used before the publication of the Third Part of my Institutes, in 1785. In some of the early editions of that book I introduced short notices of the geography and history of the United States, and this led to more enlarged descriptions of the country."

Thus we learn that geography teaching began with a few geographic notes inserted in a spelling book published just prior to Washington's inauguration.

Dr. Morse, to whom Webster here refers, was the Rev. Jedediah Morse, minister of the Congregational church in Charlestown, Massachusetts. He published in 1789 an octavo volume of 534 pages, entitled *The American Geography.* This book was, four years later, greatly enlarged and published in two volumes with the title *The American Universal Geography.* A fourth edition, extensively revised, appeared in 1801 or 1802, a fifth in 1805, a sixth in 1812, and a seventh in 1819. The *fifth* edition of 1805, and presumably all later ones, was accompanied by a little quarto atlas containing about sixty maps and entitled *A New and Elegant General Atlas,* drawn by *Arrowsmith and Lewis.*

As a special writer on geography, Morse appears to have been the first American in the field. He continued to write for many years, and after his death the son published revised editions of his father's works. As Morse's geographies, or abridgments of them made by himself or others, were extensively used in the schools, we may now learn from them something of the "state of the art," as our patent experts and attorneys would say, of geographic teaching in the early years of the century.

It is worth while to note, in passing, the high esteem in which the work done by Morse was held. The numerous editions called for and sold at home and its translation and sale abroad attest its value. Samuel G. Goodrich, who wrote so much over the name Peter Parley, referring to his boyhood school days, about 1800 to 1810, in Ridgefield, Connecticut, says:

> "When I was there two Webster's grammars and one or two Dwight's geographies were in use. The latter was without maps or illustrations, and was in fact little more than an expanded table of contents taken from Morse's Universal Geography—the mammoth monument of American learning and genius of that age and generation."

The third edition of Morse's abridgment was published in 1791. As to maps it contains only crude diagrams of the

world, of the continents, and of the United States. For the most part, therefore, it is clear that our grandparents got vague and crude ideas of geographic situation, extent, and relation, since clear views of these are not gained without maps, sometimes indeed not even with them. The points emphasized by Morse are the points which were of commanding interest and importance in his day.

Fertile soil, healthy climate, but especially transportation routes, are described in general and in particular, and are dwelt upon. The facilities which the rivers and lakes afford for commerce impressed our forefathers much more forcibly than even today the water routes to the Klondike impress the imagination of the gold-hunter.

You will recall that on the old maps the Ohio river appears as *La Belle Riviere*—the beautiful river. To the French voyageurs *La Belle Riviere* was more than a mere name. Its deep and placid waters, affording an easy and delightful natural highway for a journey almost a thousand miles long, unbroken by falls or rapids, were to them indeed beautiful. Of it Morse says:

"The Ohio is the most beautiful river on earth. Its gentle current is unbroken by rocks or rapids except in one place. It is a mile wide at its entrance into the Mississippi, and a quarter of a mile wide at Fort Pitt, which is 1,188 miles from its mouth."

This distance, 1,188 miles, has now shrunk to 965 miles.

As to the Mississippi he says:

"The principal river in the United States is the Mississippi, which forms the western boundary of the United States. It is supposed to be 3,000 miles long and is navigable to the falls of St. Anthony."

In the numerous lakes and rivers scattered over the land Morse saw a bond of union between the future settlers. He points out the ease with which a complete network of waterways might be constructed and its effect. He says:

"By means of these various streams and collections of water the whole country is checkered into islands and peninsulas. The United States, and indeed all parts of North America, seem to have been formed by Nature for the most intimate union. For two hundred thousand guineas

North America might be converted into a cluster of large and fertile islands, communicating with each other with ease and little expense, and in many instances without the uncertainty or danger of the sea."

The *Western Territory* at this time (1790) comprised what is now Ohio, Indiana, Illinois, Michigan, Wisconsin, and Minnesota. It was practically without settlers. Morse guesses that it contained 6,000 French and English immigrants and negroes. As to this region, but more particularly Ohio, Indiana, and Illinois, says Morse:

"It may be affirmed to be the most healthy, the most pleasant, the most commodious, and most fertile spot of earth known to the Anglo-Americans. The design of Congress and the settlers is that the settlements shall proceed regularly down the Ohio and northward to Lake Erie."

It will be remembered that at this early date Congress met in Philadelphia. The longitudes given by Morse are reckoned from Philadelphia. Where the future capital of the United States was to be, no one then knew. The selection of the present site was actually made by Congress in 1790. Before Morse had knowledge of such selection he indulged in this bit of speculation as to the future capital. Speaking of the future state of Ohio, then nameless, he says:

"The center of this state will fall between the Scioto and the Hokhoking. At the mouth of these rivers will probably be the seat of government for this state; and, if we may indulge the sublime contemplation of beholding the whole territory of the United States settled by an enlightened people, and continued under one extended government; on the river Ohio and not far from this spot will be the seat of empire for the whole dominion."

As to the region west of the Mississippi, it was then Spanish. Originally French by discovery and occupation, it had passed from France to Spain by cession in 1763. In the light of what it now is, a few words from Morse's speculations in 1791 as to its future throw light on the geography of his time. He says:

"A settlement is commencing, with advantageous prospects, on the western side of the Mississippi, opposite the mouth of the Ohio. The spot on which the city is to be built is called New Madrid, after the cap-

ital of Spain. The settlement, which is without the limits of the United States, in the Spanish dominions, is conducted by Colonel Morgan under the patronage of the Spanish King."

New Madrid, Morse thought, was to become a great emporium of trade unless the free navigation of the Mississippi should be opened to the United States, and this, he thought, would not occur without a rupture with Spain.

Some had thought that all settlers beyond the Mississippi would be lost to the United States. Morse discusses this at some length, and concludes with a paragraph which we quote entire:

"We cannot but anticipate the period as not far distant when the AMERICAN EMPIRE will comprehend millions of souls west of the Mississippi. Judging upon probable grounds, the Mississippi was never designed as the western boundary of the American empire. The God of Nature never intended that some of the best parts of his earth should be inhabited by the subjects of a monarch 4,000 miles from them. And may we not venture to predict that, when the rights of mankind shall be more fully known, and the knowledge of them is fast increasing both in Europe and America, the power of European potentates will be confined to Europe, and their present American dominions become, like the United States, free, sovereign, and independent empires."

These sentiments have ever taken deep root in the United States. When President Monroe, more than a quarter of a century later, wrote the State paper that has forever linked his name with the sentiment, "America for the Americans," he did not create or express new or strange doctrines, but simply gave expression to an abiding conviction of the American people.

Such in brief is a word picture of the geography of the United States at the beginning. Let us now go forward a generation, to about 1820, and note the changes. Our second and, let it be hoped, last war with Great Britain is over. By the first war political independence was won, by the second commercial freedom. Our ships might now go where and when they would, freed from hateful and hated search by any foreign power. Freedom from dependence on foreign manufactures had taken root and was making vigorous growth.

It is difficult to fully realize the burning zeal with which every one was imbued to make the United States dependent upon nothing but itself. It was not enough to be politically free. Freedom was not fully won so long as we were compelled to depend upon foreign powers for anything whatsoever. In the introduction to his little geography of 1791, Morse voices these sentiments. He says:

"It is to be lamented that this part of education (geography) has hitherto been so much neglected in America. Our young men, universally, have been much better acquainted with the geography of Europe and Asia than with that of their own state and country. The want of suitable books on this subject has been the cause, we hope the sole cause, of this shameful defect in our education. Till within a few years we have seldom pretended to write, and hardly to think for ourselves. We have humbly received from Great Britain our laws, our manners, our books, and our mode of thinking; and our youth have been educated rather as the subjects of the British king than as citizens of a free republic. But the scene is now changing. The revolution has been favorable to science, particularly to that of the geography of our own country."

The great lexicographer, Noah Webster, was inspired by the same views when preparing his dictionary; and especially did that great democrat, Jefferson, strive unceasingly to complete the independence of which the political part was definitively secured by the peace of 1783.

He would not have us reckon our longitude from a foreign meridian, or depend upon a foreign country for an ephemeris or for coast charts. Accordingly, in 1804, a meridian through the Executive Mansion was surveyed and marked on the ground as the first meridian of the United States. The name Meridian Hill survives in testimony of this. In 1807 the Coast Survey was created to accurately chart our coasts for purposes of commerce and defense; and in 1804 the famous expedition of Lewis and Clarke to the Pacific ocean expanded our political and mental horizon in matters geographic. A great system of national highways, both roads and canals, was projected and pushed forward. The practical introduction of steamboats stimulated progress. Lake Champlain was connected with the Hudson by a canal, while work upon "Clinton's ditch," or the Great Western canal, as the Erie

canal was then called, was being pushed forward with great energy. The object of this canal, as Morse tells us, was "to turn the trade of the western country from Montreal to New York."

In 1791 there were only 89 post-offices in the United States. Twenty-five years later, in 1817, there were 39 times as many; 3,459. Each day in the year (1791) the mails were carried 10,000 miles by stages and 11,000 on horseback and in sulkies. Mail was carried along one continuous route from Anson, in the district of Maine, via Washington, D. C., to Nashville, Tennessee, 1,448 miles; another mail route was from St. Marys, Georgia, via Washington, D. C., to Highgate, in Vermont, 1,369 miles. These were the longest mail routes in the United States. Postage stamps were not yet invented, and the postage on each letter, which was limited to a single sheet of paper, was 25 cents.

The beginning of the third decade, or about 1830, may be regarded as marking the decadence of that grand scheme of internal communication by canals and national highways which had hitherto filled the imaginations of statesmen and publicists. The railroad had been born and a revolution had begun, the end of which not the wisest could or can foresee. To this railroad system were we indebted, and we are still indebted, for a stimulus to geographic research, which has continued undiminished to our own day.

The twelfth edition of a school book on geography by Daniel Adams appeared at Boston in 1830. This book appears to have been revised and brought down to 1827. A few extracts from it will give a picture of the geographic knowledge then existing. He says:

"Vessels are from 5 to 30 days on their passage up to *New Orleans*, 87 miles, although with a favorable wind they will sometimes descend in 12 hours. From New Orleans to Natchez, 310 miles, the voyage requires from 60 to 80 days. Ships rarely ascend above that place. It is navigable for boats carrying about 40 tons and rowed by 18 or 20 men to the falls of *St. Anthony*. From New Orleans to the Illinois the voyage is performed in about 8 or 10 weeks. Many of these difficulties, however, now are happily overcome, and much is gained by the successful introduction of steam navigation."

The children in our schools today are asked, among other things, to set forth the advantages for commerce possessed by the Western States. This is the answer to that question which Mr. Adams furnished to their grandparents. As to these Western States, which comprise all west of the Alleghany mountains, he says:

"The remote situation of this country from the seaboard renders it unfavorable to commerce. This inconvenience, however, is in some degree remedied by its numerous large and navigable rivers, the principal of which is the Mississippi, the great outlet of the exports of these States; but such is the difficulty of ascending this river that most of the foreign goods imported into this country have been brought from Philadelphia and Baltimore in wagons over the mountains, until the invention of steamboats, by which the country now begins to be supplied with foreign goods from New Orleans."

The following passage, also from Adams, throws strong light on the knowledge current in 1827 as to the great prairies of the west.

"Pilkava prairie or plain is a high, level ground in this state (he is speaking of Indiana), seven miles long and three broad, of a rich soil, on which there was never a tree since the memory of man. Two hundred acres of wheat were seen growing here at one time a few years since yielding fifty bushels on an acre."

Missouri Territory at this time, so wrote Adams—

"Extends from the Mississippi on the E. to the Pacific ocean on the W., and from the British Possessions on the N. to the Spanish possessions on the south.

In all this great region the only features mentioned by Adams are the Mississippi, Missouri, and Columbia rivers, the Rocky mountains, and Astoria. St. Louis, with a population of 4,600, was the center of the fur trade. Similarly Detroit, in Michigan Territory, with a population of 1,400, was a fur-trading station, while western Georgia was still in possession of the Indians called Creeks, "the most warlike tribe this side the Mississippi."

"The White mountains," he tells us, "are the highest not only in New Hampshire, but in the United States. Mt. Washington, the most elevated summit, has been estimated at about 7,000 feet above the level of the sea."

Finally, as to Alaska the golden, from which so much of wealth and of disappointment is to come, our author couples it with Greenland and dispatches it in this one sentence:

> "There are also Greenland on the northeast (of N. America), belonging to Denmark, and the Russian settlements on the northwest, both of small extent and little consequence."

These citations serve to indicate the horizon of geographic knowledge 70 years ago, a horizon which was steadily widening. Stories of wondrously fertile lands west of the Alleghenies found their way to the rocky and sterile farms of the east, and a steady stream of migration to better lands, where the struggle for existence should be less severe, poured over the Alleghenies and onward toward the sunset. In the vanguard was the Government surveyor measuring out the land and subdividing it for farms. Working hurriedly in a wilderness, among native tribes not always friendly, his surveys were not, perforce, accurate, nor indeed was it important they should be. They yielded a basis for titles to homesteads and for clear and easily understood descriptions. The results of these subdivisional surveys constitute substantially the only bases for the maps for much the greater part of all of our "Great West" to this day.

Already before 1840 the question of supremacy of canal or railroad had been settled. In Peter Parley's geography of 1840 a tabular exhibit of railroads and of canals in the United States shows that there were then 46 canals, with a total mileage of about 4,800 miles, and 88 railroads, with a total mileage of nearly 7,700 miles. Progress in railroad-building demanded surveys and maps. Accordingly these were made; knowledge of geography was increased, and increased at a rapid pace. Whenever a little known region is found to possess wealth or the means of its rapid acquirement, knowledge of the geography of that region increases extraordinarily fast. Witness the increase and diffusion of knowledge as to Alaska in the past twelve months. The peaceful expanding of our horizon of geographic knowledge continued steadily and uniformly. But crises in human affairs

sometimes hasten progress; wars, rumors of wars even, sometimes make possible the seemingly impossible.

The northern boundary of the United States, from Maine to the crest of the Rocky mountains in Montana, as we now see it on the maps, was definitely settled in 1842. For more than half a century prior to that date this frontier had been in dispute between Great Britain and the United States. Repeated attempts to settle it had met with repeated failure. Boundary disputes, as we know, are ever long-lived and bitter. In April of the year 1842 Lord Ashburton arrived in Washington with full power to negotiate a treaty for settling this old and irritating controversy. Webster was then Secretary of State in the cabinet of President Harrison. Before the year had ended a treaty, now known as the Webster-Ashburton treaty, had been drafted, agreed to, signed, ratified, and proclaimed as the law of the land. Webster regarded this settlement as "the greatest and most important act of his eventful life." That the settlement was just may be inferred from the fact that it displeased both parties, and both Webster and Ashburton were criticised at home for sacrificing the interests of their respective countries.

But this treaty line stopped at the crest of the Rocky mountains, and immediately there arose the Oregon question. That question was whether Great Britain or the United States owned the territory which now comprises western Montana, Idaho, Oregon, Washington, and British Columbia. Much bitterness and angry contention followed before the 49th parallel was, in 1846, finally agreed upon as the boundary. The debates in Congress and in Parliament during the years 1842–1846, and articles in leading journals and reviews, after generously discounting their partisan overstatement, clearly portray the then prevailing knowledge, or rather, should I not say, the prevailing ignorance, as to the whole region west of the Mississippi.

Mr. Winthrop, of Massachusetts, in 1844 in the House of Representatives, cited with approval these words spoken by Benton, in the Senate, in 1825:

"The ridge of the Rocky mountains may be named without offence as presenting a convenient natural and everlasting boundary. Along the back of this ridge the western limits of the Republic should be drawn, and the statue of the fabled god Terminus should be raised upon its highest peak, never to be thrown down."

On January 25, 1843, Senator McDuffie, of South Carolina, speaking of the country now embraced in the two Dakotas, Nebraska, Kansas, and thence northwestward to Oregon and Washington, said:

"What is the character of this country? Why, as I understand it, that seven hundred miles this side of the Rocky mountains is uninhabitable, where rain scarcely ever falls—a barren and sandy soil—mountains totally impassable, except in certain parts. Well, now, what are we going to do in such a case as that? How are you going to apply steam? Have you made anything like an estimate of the cost of a railroad running from here to the mouth of the Columbia? Why, the wealth of the Indies would be insufficient! You would have to tunnel through mountains five or six hundred miles in extent. Of what use will this be for agricultural purposes? I would not, for that purpose, give a pinch of snuff for the whole territory. I wish it was an impassable barrier to secure us against the intrusions of others. If there was an embankment of even five feet to be removed, I would not consent to expend $5 to remove that embankment to enable our population to go there. I thank God for his mercy in placing the Rocky mountains there."

A writer in the *Westminster Review*, in 1846, thus describes the great plains of Nebraska, Kansas, and Oklahoma:

"From the valley of the Mississippi to the Rocky mountains the United States territory consists of an arid tract extending south nearly to Texas, which has been called the Great American Desert. The caravan of emigrants who undertake the passage take provisions for six months, and many of them die of starvation on the way."

Indeed, the question much debated at the time was, Is Oregon worth saving? Both Winthrop and Webster were of opinion that the government would be endangered by a further enlargement of territory. Mr. Berrien declared that the region under discussion was a barren and savage one, as yet unoccupied, except for hunting, fishing, and trading with the natives, while Mr. Archer said the part near the coast alone contained land fit for agricultural purposes, and there were no harbors which were or could be rendered

tolerable. And yet, out of all this hot debate and war talk, there emerged in 1846 peace, Oregon, and the forty-ninth parallel. And out of all the ominous mutterings in 1898, and the fever heat that is now at the danger line, there will emerge—I am not a prophet, but let us hope, there will emerge—white-winged peace, honorable to Spain and to us, justice for all, and freedom for Cuba.

Three years later came the discovery of gold in California. Then California, as now Klondike, set the imaginations of men on fire. Long caravans of ox teams in endless succession wended their slow way across the plains, the mountains, and the deserts to the sunset land of gold. Government surveys for a railroad promptly followed, and crude and imperfect knowledge as to the region rapidly gave place to better, though still defective, knowledge of the *Great West.*

Then came war and the need of war maps. All available agencies for their production for the use of army and navy were drawn upon, and the need of topographic maps for military purposes, hitherto clear to the few, was now made clear to the many.

In the years immediately following the civil war several events occurred which gave a fresh impetus to geography. The completion of a railroad across the continent had a profound significance and importance. It was a bond of iron which, shortening the time and distance between east and west, bound them closer in ties of affection and interest. The western pioneer of '49 and '50 could revisit his old home and friends in the east, and opportunity was afforded to many in the east to get some personal knowledge of the boundless west.

In 1867 Alaska was purchased. The discussions in Congress and out preceding and following that purchase were spread abroad and taught Alaskan geography to the masses; and yet there was little to teach, for but little was known. The government, the great agency of geographic research in this country, at once began to explore its new purchase, to survey, and to map it. This work has with varying vicis-

situdes continued to this very year, when the work of exploration and survey is, under the stimulus of gold discoveries, being conducted on a scale never hitherto attempted there. It was in that same year, 1867, that Major J. W. Powell made his adventurous voyage down the Colorado river and brought the world its first clear knowledge of the *Grand Cañon*, greatest of all nature's wonders in our land. It was shortly after this that from the Hayden Survey came tidings of that region of wonders—the Yellowstone Park.

In the thirteen years immediately following the civil war three national surveys were engaged in the west in gathering information as to the character and extent of the natural resources of the western territories—territories for the most part then containing few inhabitants except Indians. The rise of these surveys was rapid, the results secured interesting and valuable, and their rivalry and clashing inevitable. Many thousands of square miles of territory were roughly mapped out and many books and reports, both popular and scientific, were produced.

In 1878 a reorganization was proposed and the National Academy of Sciences asked to submit a plan. This it did, and submitted it to Congress. The outcome was the present U. S. Geological Survey, created in March, 1879. It replaced the prior organizations familiarly known as the Hayden, Powell, and Wheeler surveys.

The work laid out for the newly created Geological Survey was geological and its field the *national domain*. What is the *national domain?* Is it restricted to the territories and places actually occupied by the United States, or does it embrace every spot where the Stars and Stripes may float? Congress after a long debate answered this question and authorized surveys to be made in every part of our whole Union. Again, geological investigations cannot be satisfactorily made nor geological results satisfactorily exhibited without maps, topographic maps—*i. e.*, maps which show the shapes and forms as well as positions on the surface. Such maps did not exist. A fragment here and there, to be sure, existed—a

fringe of sea and lake coast; but these constituted only a bare beginning. Accordingly, in 1882 authority was given and the beginning of the mighty task of making a topographic map of the United States was begun. That work has for sixteen years progressed without interruption, and today we have contour topographical maps covering more than 600,000 square miles. In almost every state and territory in the Union work has been done, while Massachusetts, Connecticut, Rhode Island, New Jersey, and the District of Columbia are completely mapped.

That the prosecution of this work and the distribution of the maps has profoundly influenced interest in and knowledge of geography of the United States goes without saying. These maps are in the hands of engineers, of projectors of improvements, of teachers, of text-book makers, and of geographic students everywhere. The standards of school geographies have risen, methods of geographic teaching have been changed, and a better understanding of the relations to environment produced.

And thus the first century of progress in geography ends with a rate of progress both in research and in teaching never surpassed. That which has been already accomplished is great, yet it is but a small part of that which remains to be done.

ON THE COMPARISON OF LINE AND END STANDARDS.

BY

LOUIS ALBERT FISCHER.

[Read before the Philosophical Society of Washington, May 28, 1898.]

The most formidable errors in the comparison of line standards are due to the unknown temperatures of the standards, but with proper facilities, such as a room of practically constant temperature and specially designed comparators, results may readily be obtained the probable errors of which will not exceed the $\frac{1}{5000000}$ part of the standards, or 0.2 of a micron in the case of a metre. In addition to the temperature, other difficulties are, however, presented when effort is made to determine the relation of an end to a line standard—difficulties due to the indirect methods that must be employed and which unfortunately not only cause greater accidental, but introduce constant errors as well.

The method that has been employed in the more recent and important comparisons of this kind is that suggested by Fizeau. It was used at the International Bureau of Weights and Measures in 1881* to determine the relation of the Metre of the Archives to the Provisional metre, with which the present international and the various national prototypes were afterwards compared.

It was also used in this country in 1889 by Mr. O. H. Tittmann † to compare the Committee metre with the Repsold metre belonging to the United States Army engineers.

* Travaux et Mémoires du Bureau International des Poids et Mesures, Tome X.

† Bulletin No. 17, U. S. Coast and Geodetic Survey.

The Committee metre is an end standard, and prior to 1890 it was the metric standard of the United States Coast and Geodetic Survey and of the Office of Standard Weights and Measures. The Repsold metre is a line standard, and as it had been compared at the International Bureau in 1883 the relation of the Committee metre to the International metre was established by Mr. Tittmann's observations.

While the method of Fizeau * is known to every metrologist, a brief description of it here may not be considered out of place. The method depends upon the fact that the image of an object reflected from a plane surface appears to be as far behind the surface as the object is in front. This is taken advantage of by bringing opaque points or a spider thread nearly into contact with each of the end surfaces of the bar to be compared, thus making it possible to observe on the end surfaces by estimating the centre of the space between the points or thread and their reflected images. The distance between the end surfaces, as determined in this way, may then be compared with a line standard on any comparator suitable for comparing line measures.

It had been pointed out by Fizeau that if the focusing upon the points and their reflected images be imperfectly done, errors would result from the fact that only one-half of each objective is used when the end standard is in position. This conclusion was based upon the following theoretical consideration of the lens:

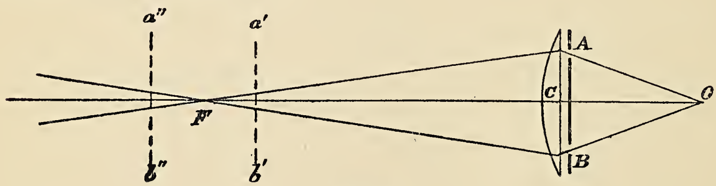


Fig. 4.

(1.) Let C (Fig. 4) be the aplanatic objective of a microscope and F the conjugate focus of the point O. Assume,

* Travaux et Mémoires du Bureau International des Poids et Mesures, Tome X.

also, that the plane of the cross-wires coincides with F. Then all rays emanating from O will converge at F, no matter where the points of incidence, A and B, are on the surface of the objective. In this case the cutting off of the rays which strike the lens at A would not affect the position of the image with respect to the cross-wires.

(2.) If, however, without disturbing the relation O C, we move the plane of the cross-wires to $a' \ b'$, then the image of the point O, formed by rays from A, will apparently be displaced, with respect to the wires, in the direction of A.

(3.) If, on the contrary, we move the plane of the cross-wires to $a'' \ b''$, the image formed by rays from A will apparently be displaced, with respect to the wires, in the opposite direction to A. Exactly the same reasoning applies to B.

In a micrometer microscope the distance between the objective and the plane of the cross-wires is fixed, whereas the distance O C is variable, for the reason that it is determined solely by estimating when the image, viewed in the plane of the cross-wires, has its maximum clearness of outline—that is to say, we attempt to make the conjugate focus coincide with the plane of the cross-wires. If, however, the distance between the observed object and objective were made too great, the conjugate focus would fall in front of the plane of the cross-wires, and hence the image would apparently be displaced, with respect to the wires, in the opposite direction to A; and if the distance were made too small, the conjugate focus would fall behind the cross-wires, and the image of the object would apparently be displaced in the direction of A.

It is evident from the foregoing that if an observer were to systematically focus in such a way as to make the distance between the objectives and the points or threads on the ends of the bar too great or too small constant errors would be introduced in the comparison; and it was to eliminate this source of error that the following arrangement, due to Cornu, was used in the International Bureau observations:

In front of each microscope a movable screen, pierced by a small opening, was so mounted that the opening could be

made to assume the two fixed positions, A and B (Fig. 4). Then, by making the opening take the two positions indicated, it was not only possible to determine when the points and their reflected images were in proper focus, but the size and the direction of the error could be determined; for, if the conjugate focus did not lie in the plane of the cross-wires and the opening were moved, it is evident that the image would apparently be displaced with respect to the wires, and the direction and amount of the displacement would determine the direction and size of the error of focusing.

Shortly after the receipt at the Office of Weights and Measures of the copies of the International metre allotted to the United States, a direct comparison of one of them, No. 21, with the Committee metre was undertaken for the purpose of settling the question of the absolute length of the Committee metre. The ends of the Committee metre in the vicinity of the axis of the bar are less perfect than the remainder of the surfaces, and hence points on the surfaces which varied from 2 to 3 mm. from the axis were selected for comparison. It was decided at the beginning to make use of platinum points instead of spider threads, as was done by Mr. Tittmann, for the reason that the air of the vault in which the observations were to be made was quite damp, and would thus make it difficult to maintain the spider lines taut.

Four groups of observations were made, the mean temperatures of which varied from 3°.75 to 22°.34 centigrade, and with probable errors which ranged from 0.23 to 0.34 microns.

While all the observations were exceedingly accordant, the value found for the Committee metre at 0°.0 centigrade differed by $3^{\mu}.26$ * from the value derived from the 1889 observations, the values being as follows:

1889.......... C. M. = 1 metre — $0^{\mu}.38$ at 0°.0 cent.
1895.......... C. M. = 1 metre + $2^{\mu}.88$ at 0°.0 cent.

The movable screen of Cornu was not used in either of the comparisons referred to, and it is therefore extremely prob-

* One μ = one micron = one-millionth of a metre.

able that part of the discrepancy in the two results is due to the observers having adopted different standards in focusing. The difficulty in determining when the points and their images were in focus was increased by the poor reflecting surfaces of the Committee metre, which rendered the reflected images much less perfect than the points themselves.

The difficulty of providing the comparator used in the later observations with the necessary adjustments to render the use of the movable screen possible, and also the inferior surfaces of the Committee metre, led to the consideration of other methods.

Several special contact methods for comparing line and end standards, notably that of Airy,* had been suggested and used, but none of them seemed applicable to this case.

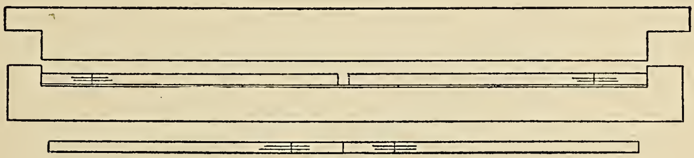


FIG. 5.

Auxiliary abutting pieces have been used for many years in the Office of Weights and Measures to determine the distance between the interior surfaces of the matrices (Fig. 5) of the State yards † on the Saxton Comparing Machine. ‡

The manner of using these pieces is exceedingly simple. The abutting ends are first placed in contact with surfaces of the matrix, as shown in Fig. 5, and the distance between the lines ruled upon them is compared with the distance between 0 and the 30th-inch stop of the Saxton Comparing Machine. The abutting ends are then placed in contact with one another and the distance between the lines is compared with the space between the 30th to 36th inch stop. The result of these operations is that the length of the matrix is referred to the dis-

* Philo. Trans. of the Roy. Soc. of London, vol. 147, part iii, p. 685.

† Standard yards made for the States.

‡ Report of the Secretary of the Treasury on the Construction and Distribution of Weights and Measures, Wash., D. C., 1857.

tance between the 0 and 36th-inch stop, and it only remains to determine this distance, which may easily be done by comparing it with a standard yard.

The auxiliary pieces just described suggested a method for comparing the Committee metre, also depending upon the use of abutting pieces, the construction of which, however, required considerable mechanical skill. The principal requirement was that the lines ruled upon them should be so close to the abutting surfaces that when the pieces were in contact with one another the lines on both should be visible in the field of one of the Comparator microscopes. The distance between the lines could thus be measured with the micrometer screws. This condition would also make it possible to directly compare the combined length of the Committee metre and abutting pieces with Prototype No. 21.

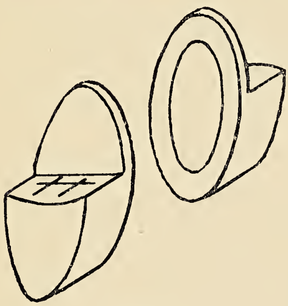


Fig. 6.

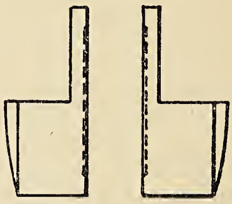


Fig. 7.

Two platinum pieces meeting all requirements were constructed in the Instrument Shop of the Coast and Geodetic Survey, of which Fig. 6 is a perspective and Fig. 7 a side view.

Each of these pieces carries upon its horizontal surface a single line ruled parallel to the abutting surface and only 0.8 of a millimetre from it. In addition, two parallel lines about 0.5 mm. apart are ruled perpendicular to the contact surface and across the first line. All observations were made on that portion of the single line between the two parallel ones.

The abutting surfaces are flat discs 6 mm. in diameter, and the material is turned out of the central portions, so that only a ring about 0.7 mm. wide was in contact with the ends of the Committee metre.

Fig. 8 shows the abutting pieces when in contact with one another, and Fig. 9 when they are in contact with the Committee metre.

In both cases the pieces were pressed in contact by means of weak springs. No attempt was made to measure this pressure, for the reason that some experiments which were made proved conclusively that the pressure could be varied considerably without appreciably affecting the distance between the lines.

FIG. 8.

FIG. 9.

In order to determine the distance between the lines on the abutting pieces when they are in contact with one another it is essential that the line surfaces be in the same plane. This was effected by the following simple device: Two small pieces of plate-glass G G (Fig. 10), about 1 by 1.5 cm., were laid upon a large plate of glass with just sufficient space between the edges of the smaller pieces to admit the projecting rings of the abutting pieces when in contact. Plaster of Paris was then poured over the small glass pieces and allowed to harden. The pieces of glass were thus "set" in the plaster, and the whole was then separated from the large glass plate. The plaster of Paris was then trimmed with a knife, and it was likewise removed from between the imbedded pieces of glass, after which the device was examined. Since the two imbedded pieces of glass were in contact with the flat glass plate referred to, they were necessarily in the same plane, unless disturbed by the liquid plaster of

Paris. In order to test whether this had occurred, the reflection of a straight rod or string from the two surfaces was viewed. If the thread or rod appeared continuous, except where it was interrupted by the space between the two pieces of glass, the appliance was considered ready for use.

The use of the arrangement was likewise very simple. The upper parts of the contact surfaces, namely, the parts above the line surfaces, were placed in the opening between the pieces of glass, as shown in Fig. 10, and when the line surfaces were in contact with the glass the pieces were clamped together with a U-shaped spring, after which they were mounted on an adjustable tripod under the microscope. By means of the tripod the plane of the two surfaces was made

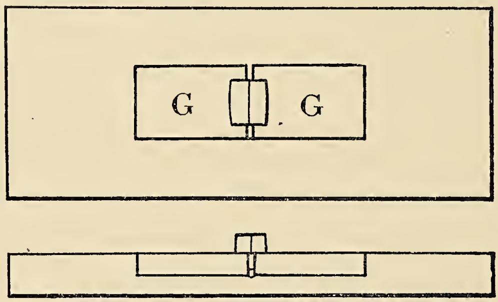


Fig. 10.

perpendicular to the axis of the microscope, and the distance between the two lines was then ready to be determined. A slight error, always operating to make the distance between the lines too short, would result from small inclinations of the line surface.

To determine what inclination would be permissible, let d equal the true distance between the lines, which is approximately 1600^{μ}, and α the angle of inclination. Then the error would be $d \cos \alpha - d$; or, $d (\cos \alpha - 1)$. Substituting for α, $10'$, $20'$, $30'$, we get the following errors: 0.01, 0.03, 0.06 microns.

It would be an easy matter to keep the inclination below $10'$, and I am satisfied such was the case in this work.

Six determinations of the value of the space were made in all, each determination consisting of six measurements with each of the two micrometers belonging to the Comparator. Between them the surfaces were separated, readjusted, and mounted on the tripod under the microscope.

The mean of the six determinations gave $1627^{\mu}.32$ as the
$\pm.16$
distance between the lines.

Three independent comparisons, by as many observers, of the combined length of the Committee metre and abutting pieces were made with No. 21, between which the abutting pieces were readjusted and exchanged.

It is unnecessary to describe in detail the adjustment of the abutting pieces on the ends of the Committee metre; methods for doing this would naturally suggest themselves to any one attempting to use the method. It is, however, important to keep in mind that the end surfaces of the Committee metre are perpendicular to the axis of the bar, and hence, when the pieces were in contact, the contact surfaces were parallel and separated by the length of the metre.

The result of the comparisons with No. 21 gave the following value for the combined length at 0°.0 centigrade:

$$\text{C. M.} + \text{abutting pieces} = 1^{m} + 1625^{\mu}.97 \atop \pm.08.$$

Subtracting from this the value of the abutting pieces found above, we get—

$$\text{C. M.} = 1^{m} - 1^{\mu}.35 \atop \pm.18,$$

a result that is smaller than either of the former ones referred to.

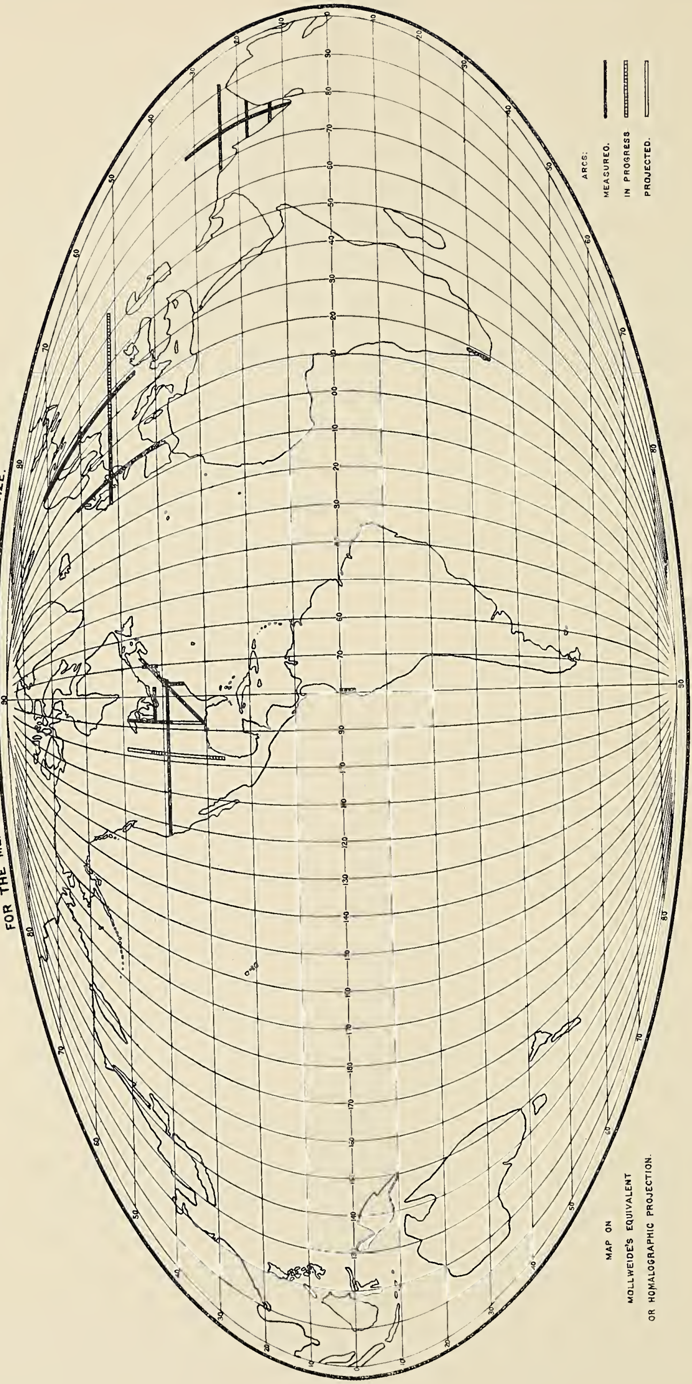
The condition of the end surfaces is doubtless responsible to a great extent for the disagreement of the results by the different methods, but it is difficult to account for the small value due to the last method. One would naturally expect it to give the larger value, since the value determined in this way is the length between the higher points of the surfaces.

I regret that circumstances were such that further experiments with a bar having more perfect end surfaces could not be undertaken to fully test the method. I see no reason, however, to doubt that it is at least as reliable as the optical method even when used in connection with the perforated screen. Indeed the most recent experience of the International Bureau of Weights and Measures * has been such as to almost warrant the cessation of the use of the optical or Fizeau method. It has been briefly this: Six end standards, five of which were constructed for the governments of England, Russia, Germany, Austria, and Bavaria, were compared with a line standard by the optical method. They were afterward compared with the same standard by means of a contact method, the only detail of the method given being that the contact surfaces of the abutting pieces were rounded. The two sets of results, greatly to the surprise of the observers, differed on the average by 3.5 microns, or by one part in 300,000, the contact method giving the larger results for the end standards. Suspecting that the objectives of the microscopes used in the first comparisons were responsible for the discrepancies because of imperfections, the first observations were repeated, the only difference being that the original microscopes were replaced by two others. The results of the last observations agreed perfectly with those obtained by the use of the contact method, and the conclusion was reached that the first results were erroneous.

The relation of the present International metre to the old Metre of the Archives was determined by the Fizeau method, and the question naturally arises as to whether the assumption heretofore made that the bars are equal can now be accepted. I am of the opinion that it cannot, but that a recomparison will be necessary.

* Comité International des Poids et Mesures, Procès-Verbaux des Séances de 1897, pp. 55–61.

FOR THE MEASUREMENT OF THE EARTH'S FIGURE AND SIZE.



PRINCIPAL ARCS—MERIDIONAL, PARALLEL, AND OBLIQUE.

RECENT PROGRESS IN GEODESY.*

BY

ERASMUS DARWIN PRESTON.

[Read before the Society April 30, 1898.]

I. THE MEASUREMENT OF THE EARTH.

Whatever may be the finally adopted size and shape of the earth, we are now in a position to modify materially some generally accepted notions in regard to it. During the course of this paper some recent facts bearing on the shape of the geoid will be brought forward, and it will be shown that a new theory of the earth's collapse is thereby strengthened. For more than twenty years the argument for a solid earth, deduced from the phenomena of precession and nutation, has been abandoned. Astronomers and Geologists are now agreed as to the plasticity of at least a thin shell next below the external rocks. This being admitted, the form assumed by the earth's shrinking envelope becomes a matter of study, and all observations bearing on this point should receive their due share of consideration. It is for this purpose that attention is now called to three arcs—two in Europe and one in the United States—that have been measured parallel to the equator in quite recent times. In order to fully realize the gigantic strides made since the figure of the earth first became a subject of inquiry, let us look for a moment at the different steps in the process. Let us see how the human mind, first groping in the dark and trying to reconcile preconceived ideas with natural appear-

* Published by permission of the Superintendent of the United States Coast and Geodetic Survey.

ances, passed successively through the belief in a flat disc, a sphere, an ellipsoid, and a geoid, and finally, as observations became more and more exact and the requirements of theory demanded that new conditions should be satisfied, we have passed the stage where any better *mean* figure can be supplied and a new line of attack must be devised. All our future investigations must be limited to the *deformations* of the ellipsoid; and whether they are revealed by the pendulum, by the measurement of arcs, or by whatever process, we shall have an accumulation of data from which may be deduced a figure of the earth compatible with the known laws of nature. The spherical shape of our planet was confirmed by the simplest observations. The ellipsoid deduced by Newton from purely theoretical considerations was confirmed by geodetic measurements in Lapland and Peru, and it now seems likely that the tetrahedral shape will be sustained by recent measure of parallel arcs.

Before taking up the tetrahedral theory we shall briefly recall a few of the steps in the development of our knowledge of the earth's figure. The belief in a flat disc dates from the Songs of Homer. Notwithstanding the fact that the simplest observation on the seashore shows the inadequacy of this theory, it continued to prevail for seven centuries. Pythagoras then asserted the doctrine of the sphere. This, however, was not seriously considered for 300 years. Then Aristotle took up the question, weighed the evidence for and against, and came to the conclusion that the disc idea was untenable. Another century passed before it occurred to any one to actually measure the earth's circumference. Eratosthenes did this by observing at two points the direction of the sun's rays with reference to a vertical line. Some one else applied the same principle 100 years later, using a star and referring the directions to the horizon, so that at the beginning of the Christian era it was pretty well established that the earth was a sphere, and that its diameter was about eleven million meters, as we define that unit today. The error of a million meters in this

result is large, but is quite admissible when we consider the circumstances. The distance between the stations was roughly measured, the direction of the sun's rays was erroneously assumed to be vertical at one of the points, and the stations were not quite in the same meridian, a desirable condition at this stage of the problem, because in order to make the reduction to the meridian a knowledge of the size of the earth is requisite, which is precisely the information sought.

Europe gave little thought to this question for fifteen centuries after the birth of Christ. Then comes that remarkable measure of Fernel, who by a crude method determined the earth's dimensions with an error of only one-tenth of one per cent. For the first time, in Europe, the latitudes of the terminal points in the arc were observed and the distance between them measured. This determination served to open the way for modern work, and from this time on, men ceased to look for new methods, but bent their energies towards increasing the accuracy of an existing one which had been universally adopted. The greatest stride in this direction was made by Snellius, who first introduced triangulation to measure distance, and succeeded in reducing the error in angular measures to about one minute. Activity was now redoubled, and nations began that generous rivalry in the prosecution of the work which has been productive of all our best information on the subject. Since the year 1600 the question has been taken up by many civilized nations, and the result has simply been to perfect our knowledge and give closer and closer approximations to the value sought. Two points of interest occur. From the French work it appeared that the earth was flattened at the equator instead of at the poles. As this result implied an error in Newton's theory of gravitation, the French Academy sent expeditions to Lapland and Peru in order that no doubt might exist. Their labors settled the question in favor of an oblate spheroid.

Passing separate determinations, we come to the work of

Bessel, who in 1841 collected all available data and deduced results which were universally adopted until 1866, when Clarke by the same process gave values which are now regarded as an improvement on those of Bessel. This brings us to the strictly recent work, and leads to an examination of the measurement of the 52d parallel of north latitude in Europe and the 39th parallel in America. To this might be added a short measurement on the 56th parallel, also, in Europe. The results all point in the same direction, namely, that the curvature is greater than would be required on an oblate spheroid of the dimensions of our earth. The fact being established that all three of the parallel arcs indicate a bulge in the continental profile, the way is open for the application of theories that would bring about such a result, and that theory which seems to provide most consistently for such phenomena is precisely the tetrahedral one of which mention has already been made. First, as to the facts. Clarke's spheroid is larger and flatter than Bessel's. It represents that regular figure most nearly coinciding with the actual earth. Measurements on the 56th parallel show a greater curvature than would be required for the mean figure. It is true that the arc is a short one, but the evidence is unmistakable as far as it goes. Then comes the great arc of 70° on the 52d parallel, which has a radius of curvature 486 meters shorter than would be required on the Clarke ellipsoid, and finally in our own country the transcontinental arc from Cape May to San Francisco indicates a greater curvature than is required to fit the adopted shape of the earth resulting from the best modern data on the subject. The principal arcs measured and in progress in North America are shown in Plate 12.

Now as to the tetrahedral theory. To begin with a simple example, it is known that rubber spheres immersed in water tend towards a tetrahedron. The reason is evident. The sphere of all geometrical bodies has the least surface for a given capacity. The tetrahedron, on the contrary, has the greatest surface for the same condition. When pressure is

PRINCIPAL ARCS IN NORTH AMERICA, MEASURED AND IN PROGRESS.

exerted, the tangential strains find relief in the easiest possible way. This is brought about by the transition from a sphere to the tetrahedron. When the earth contracts the same conditions exist, and the shrinking envelope assumes a figure giving a depression at the north pole and an elevation on the continents of America, Europe, and Asia. This requires a depression between the two last continents which as a matter of fact existed in preglacial times. It seems to be a remarkable coincidence that the three arcs of parallels measured up to the present time should all agree in showing the curvature of the earth in their locality to be greater than the mean figure requires, and, as far as conclusions can be drawn from these results, we are forced to admit that the earth is collapsing in the form of a tetrahedron. One apex is found at the south pole, a base at the north pole, and the edges follow in general the continental upheavals. It may be worth while in passing to revert briefly to the geodetic measures necessary to determine the earth's figure, and also to note the fact that in all this work the greatest attention has been given to the effect of plumb-line deflections on the length of the arc. The equations of Laplace, which exercise a control, and which also demand a consistency between the deflections in longitude and those in azimuth, have been steadily applied; so that there is little danger that the final arc as given in angular measurement is enough in error to invalidate our conclusions as to the real radius of curvature. The control is simply this: While we only have one method of determining the deflection in the plane of the meridian, there are two ways of doing this when it is required to find deflections in the plane of the parallel. It appears that the discrepancy between the astronomical and geodetic longitude, multiplied by a factor depending on the latitude of the place, is theoretically equal to the discrepancy in azimuth also multiplied by a function of the latitude. This furnishes a simple and effective check, and enables us to use all our astronomical observations in arriving at a consistent and most probable value of the great curve under consideration.

With these safeguards thrown around our procedure, we may with confidence draw conclusions that are both legitimate and sound.

II. Methods of Determining the Earth's Figure.

The size and shape of the earth may be found either from two meridional arcs or two longitudinal ones, or finally from a simple oblique arc. The first method was exclusively employed during the last century, because it was possible to determine latitudes with more precision than longitudes; but in recent times the electric telegraph has so simplified the determination of the latter and has given such increased accuracy to the result that the last two methods may now be employed with entire success. All three are comparatively simple in their conception, although the problem considered in detail becomes an intricate and troublesome one. The individual steps are these: For the first case we have only to measure the length of two lines running north and south and observe the latitudes of the extremities. From this data the flattening is first found and afterwards the absolute length of the earth's axes. This method was used in the work which gave us our first knowledge of the relative lengths of the polar and equatorial diameters of the earth, and the arcs of Lapland and Peru, which have become classical in geodetic literature, were utilized in this way. These measurements have now little more than historic value. Nevertheless, their great importance when executed may be judged from the fact that on their testimony the great question was decided as to whether the poles were nearer the center of the earth than the equator. This is a query that every schoolboy will answer today, but as late as the middle of the last century no one knew, and thousands of dollars were spent by the French in their efforts to solve the problem once for all. The arctic and the equatorial work decided the question, and with this contribution to our knowledge it may be said that their usefulness ceased, although the result

is still given some weight in our more recent discussions, and probably influences the final conclusion to a certain extent.

The second case, that of determining the earth's figure by means of longitudinal arcs, is rapidly coming into use on account of the application of electricity to astronomical problems. The method finds application in our great transcontinental arc from Cape May to San Francisco, and we may feel legitimate pride in knowing that no other nation has done so much in this particular way. The fundamental idea, like the preceding one, is simple. We measure the distance between two points lying nearly or exactly east and west, determine their latitudes, and also their reciprocal direction. The latitudes need not be accurate when the observations are near the equator, and when the line is nearly east and west its direction need only be approximately known. A second arc gives similar relations, and by means of both we can determine the earth's compression and its absolute size.

A third way of getting at the same result is by an oblique arc such as is just now being completed between the northern part of Maine and the southern part of Alabama, running through its middle part along the crest of the Appalachian chain. Here we have a case where the direction between the extreme points is of much more importance than in the last method. In fact, it is one of the essential features of the work. As usual, the latitude of the extreme points must be found, and with this data and the reciprocal azimuths the flattening of the earth may be deduced. This comes from the establishment of a relation between the four magnitudes just cited and the eccentricity. The simple addition of the *length* of the line joining the two points to the previous data enables us also to find the size of the earth and thus completely determine its figure. It is evident that the method is not applicable when the line is nearly north and south or east and west, nor when the work lies near the equator. The most favorable conditions are when the arc is quite oblique to the meridian and above middle latitudes.

This statement exhausts the three independent methods of determining the earth's size and shape. But in a country like the United States, where we are liable to have long lines running in every conceivable direction, a general method for all oblique lines finds frequent application, and, without going into details, it may be stated, first, that it is desirable to utilize all available data, and, second, to so combine them that consistent results will follow. If we take any line at random on the earth's surface and determine its length, the geographical positions of the extreme points, and the directions of each point from the other, we have six measured values, which combine in one case all the data used in the three independent methods. This gives sufficient matter to completely solve our problem, and, moreover, gives us one superfluous condition, which must be made to harmonize with all the others. Here comes in the great work of geodesy, viz., to get from all the measures one consistent and satisfactory result. Take the astronomical difference of longitude between the two points and their given latitudes. This data enables us to locate the points on a sphere of *any* size. Add to this the *length* of the line, and we are limited to a sphere of a given magnitude. Add the direction of one point from the other, and we are forced to change from a sphere to an ellipsoid of revolution to satisfy the given data. Add still the reciprocal direction, and we have one condition more than is necessary for the complete solution of the problem, and the necessary discrepancies find adjustment by the method of least squares. In this reconciliation between measured values, which are always more or less subject to error, and theoretical conditions, the expedient so often employed in scientific work is adopted. Approximate values for the earth's dimensions are introduced and, by differentiation, relations are established between the corrections to the approximate values and the measured ones. It is true that certain suppositions are made that are not strictly true, but the error introduced through this procedure always falls within the degree of accuracy sought in the final result. For example, in a system

of differential equations involving our available data *the length* of the line joining the points in question is regarded as a constant. This means simply that, in comparison with the other variable quantities, an error in the length of the measured line has little or no influence in the adjustment of discrepancies.

In fact, the inherent nature of the observations must always be considered, and we are often restrained and hampered in striving after a certain limit of accuracy for the reason that geometrical conditions render one result much more accurate than another. Consider the equations of Laplace already cited. We are able to get the deflection of the plumb line in an east and west direction in two ways, by determination of longitude and azimuth; but while an error of one second in the geodetic longitude of a place is not admissible, it is quite within the limit of possibility that the geodetic azimuth should be erroneous by such amount. Since both of these data can be applied to determine the deflection of the plumb line, it is evident that they furnish results entitled to very different degrees of consideration. In general, it may be said that the accuracy attainable in the result by the two methods (longitude and azimuth) have about the same relation that the earth's radius has to the distance between the two points. The principal meridian, parallel and oblique arcs, measured, in progress and projected, to the present time are shown in Plate 11.

These are the principal steps in the work, but in the execution of the necessary detail we meet many modifying considerations. Prominent among these is the question of the deflection of the plumb line. It is well known that the so-called vertical lines, as defined by a freely suspended weight, are not perpendicular to the surface of our ellipsoid of revolution. Every change in the density of the underlying strata, every elevation and depression on the earth's surface, has its effect on the plumb bob, and when we make astronomical and geodetic observations based on a certain assumed vertical we are by no means sure that our measures are cor-

rectly referred to the mean surface of the earth. When we assume that the difference of longitude between Cape May and San Francisco is correctly measured, as far as our instrumental means permit, we may be several seconds in error, owing to the attraction exerted on our plumb bob by the mountains or the sea. Just here the equations of Laplace bring us a precious aid, in that they make it possible for us to treat these anomalous features so as to arrive at a result less affected by the influence of the form and density of the earth's crust; the real significance of Laplace's equations being that with our present refined methods in the telegraphic determination of longitude it is possible to establish for a geodetic line that has been completely determined in latitude, longitude, and azimuth a conditional equation which is independent of the deflection of the plumb line. Generally speaking, it may be said that the dimensions of our mean ellipsoid of revolution can be determined with great precision by measurements on the geoid which approximately coincides with the ellipsoid. One word about the best reference for the deflections of the vertical. It is now—indeed, has been for some time—most emphatically brought out that some standard must be adopted. Of course, relative deflections may be treated without making any assumption as to the absolute direction of the vertical line; but when it is a question of considering all such determinations, it has been proposed to refer them to a mean ellipsoid of revolution whose center is identical with the center of gravity of the actual earth, whose smaller axis coincides with the earth's axis of revolution, and whose surface most nearly agrees with its actual form. All deflections can thus be referred to a standard direction.

While we are on the question of the earth's figure we may take time to notice some peculiar conditions consequent upon its actual shape. When we speak of the earth as being flattened at the poles, the idea usually conveyed is that were the earth small enough to be seen at one view its ellipsoidal shape would be quite apparent. Many facts have been cited

by writers to show that no difference would be noticeable between the length of its polar and equatorial dimensions. Let us compare the length of the shortest line joining two points on the earth's surface and the path actually traced by the line of sight of a theodolite. These lines have essentially different characters, the latter being a plane curve, while the former is of double curvature. The Coast and Geodetic Survey is now tracing the boundary betwean California and Nevada, running from a point in Lake Tahoe in a southeasterly direction to Fort Mohave. This line is several hundred miles long and will furnish material to bring out the points in question. It may appear paradoxical, but such is nevertheless the case, that if it were possible to set up an instrument at one end of this line and sight to the other, and if a man were required to pass over this line of sight he would not follow the same path that he would had he started from the other end and complied with the same conditions. This is due to the earth not being a perfect sphere. It is understood, of course, that the instrument is in both cases set up vertically at the two stations. What difference in length is there, then, between either of these lines and the shortest line joining the two points? for in neither case would our traveler traverse the shortest path. The difference is not great, and in this we realize how nearly equal, even for great distances, the lines on our planet are to those on the surface of a sphere. The shortest line between Washington and Eastport, Maine, is about $\frac{1}{1000}$ of an inch less than a plane curve joining the two points. Between Lake Tahoe and Fort Mohave the distance is 404.5 miles. The azimuth of the line is about 45° and its middle latitude not far from 37° north. The difference of length between the shortest line on our ellipsoid and a line traced under the conditions stated is not quite 4 microns (or about $\frac{1}{6000}$ of an inch) and the lines of sight observed from either end towards the other would differ by only 2″.2 of arc. If two observers, having adjusted their instruments in the usual manner, one at each end of the line, should sight to the

other end it would be found that the lines of sight would be separated at one point by nearly six feet ($1^m.8$). Calculation shows that the area included between the two lines, which on a sphere would be identical, but which on account of the ellipsoidal form of the earth really diverge, is equal to a good-sized farm, being no less than 145 acres.

The pursuit of scientific truth is often accompanied by unexpected discoveries and the revelation of new difficulties. The fact that the earth is traveling through space at the rate of about 18 miles per second necessitates a correction to our astronomical observations dependent on this motion; and because it is not only flying along its path at this enormous speed, but also on account of its revolving on its axis, we are obliged to introduce corrections to reduce observed facts to an uniform basis. We can no longer ignore the convergence of the equipotential surfaces of a rotating spherical body, and observations for latitude as well as those for leveling must be corrected accordingly. The latitude of a place above the sea level as determined by observation is always greater than that of a point vertically under it on the plane of mean sea level, and the relative height of any point determined by spirit-levels when the line is in the meridian is greater by actual determination than it would be were the earth not subject to the influence of attraction and rotation. The value obtained for the elevation of a point 400 feet above the gulf of Mexico, depending on a line of levels through a distance of 500 miles, may be nearly two inches in error—that is to say, that on account of the revolution of the earth a line of precise levels extended from south to north and increasing in elevation gives a height for the terminal point two inches greater than is actually the case.

III. Aberration of Light.

One of the greatest accomplishments in scientific work is the ability to extract from a great mass of observations all the information that they are capable of yielding. The

derivation of empirical formulæ embodying a fixed law of nature may, besides establishing the truths which were the original objects of the investigation, accidentally bring out an unsuspected fact. Some years ago it was discovered that terrestrial latitudes were subject to a change, and that the law of these changes could be formulated in a simple linear equation containing two unknown quantities. When the equations of condition were formed, which theoretically should entirely satisfy the observations, and when a solution was effected giving results which were supposed to leave outstanding only accidental errors, there appeared to be systematic discrepancies. Moreover, the differences showed a well-defined, uniform change, increasing at one season of the year and decreasing at another. This phenomenon was none other than the effect of the aberration of light. It is well known that the velocity of light is about 10,000 times as great as that of the earth, so that while the earth travels one mile in its orbit, the ray of light by means of which we take cognizance of any celestial object and make our measurements has traveled 10,000 miles. This amounts to saying that our telescope must be inclined at a slight angle in order to receive the ray of light, the angle depending, of course, on the direction of the earth's motion with reference to the observed ray, and the so-called "constant of aberration" is nothing more than the maximum displacement of the apparent position of the star. This, of course, obtains when the motion of the earth is at right angles to that of the ray of light. With these facts before us, it is quite evident that the observations for the variation of latitude contained not only data sufficient to show how the latitude was changing, but also the effect of the aberration besides. They could therefore be utilized to determine this last quantity, and after that to find the size of the earth's orbit. This was suggested by Professor Newcomb, and has been done in the case of the observations made at Honolulu and San Francisco, and the results of the work have now been published in Appendix 10, Report of the Coast and Geodetic Survey for 1896. In

this report it is shown how nearly 7,000 equations are used to find the quantity sought. It is extremely gratifying to note that, although the original observations were made to study only changes of latitude, they embodied sufficient material to determine with precision one of the fundamental constants of astronomy.

The final values obtained were:

Constant of aberration...........	20″.458
Solar parallax..................	8″.808
Sun's distance (miles)............	92,820,000

IV. The International Geodetic Association.

It is now proposed to state briefly and in very general terms what has been done by the International Geodetic Association in the question of the measurement of the earth. The first idea of coöperation on a grand scale seems to have come from General Baeyer. In 1861 he wrote to the Prussian Minister of War recommending that the nations of middle Europe should combine forces and devote themselves to the solution of the problem. He called attention to the fact that France had undertaken the work on a large scale in the 18th century, and England and Russia in the 19th, and that the eastern and western parts of the continent were much farther advanced in this line of work than his own country. At this time only three arcs of the meridian and three arcs of the parallel had been measured in Europe, but they had already begun to notice the anomalies in the direction of the plumb line and were unable to explain the reasons therefor. The first and most natural supposition was the attraction of the mountains; but when deflections of the plumb line were found on extended plains, and, moreover, when, as they then supposed, the great Himalayas exercised no appreciable effect, they were led to suppose great changes of density in the earth's surface. Perhaps this phase of the question stimulated as much as anything else the coöperation of the different governments. In any event, during the month of Oc-

tober, 1864, there was effected an organization for the measurement of arcs in middle Europe. The first general report shows that nineteen States gave support to the project. The general plan remained unchanged until 1886, when the Middle European Association was merged into an international one and nations from all parts of the world became parties to the convention. The organization was continued for a period of ten years. In 1896 new powers were assumed by the organization, and a new convention, to hold for ten years, was drawn up. To this last convention the principal nations, except England, have agreed, and have through diplomatic action become contracting parties to the agreement. This, in brief, is the origin and growth of the present organization. An outline of its methods of work and the results attained will show what is being done by concerted national action to determine the size and shape of the earth. From the beginning of the work up to 1887 the results were largely of local importance. Each State gave reports on the operations within its border and which were intended primarily to serve as the basis for a map of the country. The triangulation, measure of base lines, astronomical observations (such as latitude, longitude, and azimuth), precise levels, and tidal observations found their greatest use locally; but in the last ten years questions have been taken up which are of the greatest interest to each individual country and to the world as a whole, and so when investigation is made of the variation of latitude, the force of gravity, the aberration of light, deflections of the plumb line, etc., we are getting results from which all nations profit alike; and it is precisely these larger universal questions to which the International Association is now giving a large share of its attention. It is not worth while to pass in review at present the details of the work of the organization. Suffice to say that practically all the nations of Europe and some in America and Asia are devoting their best scientific energy to this line of thought, and the publications of the association are replete with reports of the greatest interest and value on studies of the external features of the planet on which we live. Passing over what has been done incident

to the regular work of every trigonometrical survey of a country, I shall call attention to a subject already referred to, which promises to furnish novel results in the near future.

V. The Variation of Latitude.

The International Geodetic Association now proposes to establish four stations as near as practicable at equal distance around the earth and all within half a mile of the same parallel of latitude. When it was discovered that the latitude changed, and that we were at one season of the year about 60 feet nearer the equator than at another, the result was so startling that many observatories engaged in the work of observing the latitude. The outcome was that the motion of the earth's axis could be traced with reasonable accuracy from about 1888 to the present time. But the trouble is that the result was to a certain extent vitiated by the fact that the star places were uncertain, and although by an ingenious method of combining the observations this defect to a large extent disappeared, nevertheless the observations did not yield the desired precision. Now it is proposed to so choose the stations that the results will be entirely uninfluenced by any errors in the accepted position or proper motions of the stars. This can be done only by locating all the points of observations on the same parallel of latitude. Then the further question arises, at what distances apart shall they be? Mathematical considerations show that the most accurate determination of the quantities in question is attained when the stations are equally distant around the earth. This would seem to be the natural supposition. Mathematics, after all, is only common sense. So that if three stations are adopted they should be 120° apart; if four, 90°. But there comes in the condition that the configuration of the continents will not permit an equal distribution, so that a compromise and adjustment has to be made between the mathematical, physical, and social conditions. The importance of the last named must not be underestimated. We may have trained observers, but they cannot make the best

observations either in a desert or in a country where the comforts of life are unattainable. Still another condition must not be forgotten. In a country where earthquakes are frequent we may have sudden changes in the direction of the plumb line. Observations which are to bring out variations in the latitude, whether they be continuous and comparatively rapid, or of long duration, must be free from local disturbances of this kind; and then the weather conditions must be thought of. At some places one would not get three good nights in a month. No latitude station would be possible in such a neighborhood. The location of the stations is to be decided therefore in this way. A single pair of stars observed at three stations gives the required data. The position of the pole is determined from two coördinates, and on the position of the station as regards longitude depends the precision of the determined quantities. The weight of the result in a mathematical sense is a function of the longitude of the stations, and if we have any number of stations on the same parallel, we may estimate in numerical values the precision of the determination of the position of the pole. Any other parallel and any other combination of stations can be similarly expressed, and our task is simply to find from all the different possible combinations of stations on separate parallels that one which gives a maximum value for the precision. With this end in view, no less than eighteen combinations, of which fifteen are in the northern hemisphere, have been examined by Professor Albrecht. From a mathematical point of view only nine were acceptable, and from these nine it was necessary to choose four which were physically practicable and which at the same time offered the necessary social conditions. These stations have not yet been definitely decided upon, but they will presumably be on the parallel of latitude 39° 8′, and, besides, two will almost certainly be in the United States. The others will be, one in Japan and the other in Italy. Of the American stations six have been critically examined, viz., Ukiah, in California; Dover, in Delaware; Gaithersburg and Annapolis Junction, in Maryland, and Round Hill and Leesburg, in Virginia.

It is proposed to carry on latitude observations of precision at two of these stations for a period of at least five years, possibly longer, at the end of which time sufficient data will be at hand, when taken in connection with the Japanese and Italian work, to predict the position of the pole with much greater precision than could be done hitherto. The cost of the entire work will be about $10,000 annually, but the International Geodetic Association has considered the benefit to science commensurate with the outlay, and the project will be taken up in the near future.

In this connection we may remark that, although the method just outlined is without doubt the most perfect that can be devised where several observatories contribute to the result, the same end may be attained by observations in two localities. Such a method has been proposed by Professor Harkness, and some of the necessary observations are now going on at the U. S. Naval Observatory. Making use of the fact that two stars, each of the first magnitude, culminate about the same time and on opposite sides of the zenith, he has availed himself of their position and brightness to make observations at every meridian passage day and night through the entire year. The simplicity and elegance of the procedure lies in the fact that an effectual check is secured through the invariability of the sum of the zenith distances of the two stars, whatever may be the change in latitude. The change in the difference of their zenith distances is, moreover, twice the latitude variation. Since the effect of aberration will necessarily have its influence on these results, it is proposed to make it the subject of a separate determination, utilizing four other stars, when the effect has its maximum value. Greater accuracy is therefore secured by observations under the most favorable conditions, and the effect of aberration can be successfully eliminated. The complete motion of the pole is then obtained by combining the observations on α Lyrae and α Cygni with those made at some station 6 hours east of Washington, and thus practically the same result will appear from two stations as would be furnished by four in the scheme above mentioned.

THE SECULAR CHANGE IN THE DIRECTION OF THE TERRESTRIAL MAGNETIC FIELD AT THE EARTH'S SURFACE.

BY

G. W. LITTLEHALES.

The observations and results that I am about to present relate to the directional elements of the earth's magnetism at many important stations in remote parts of the world, during the seventeenth, eighteenth, and nineteenth centuries. In view of the desirability of preserving the collection of observations upon which the present results depend, and of the great variety and general inaccessibility of the works of reference from which they are drawn, the observed values of both declination and inclination are stated in full, with the names of the observers and the sources of information. Considerable data are thus made available for other workers in the same field, and the books are referred to in which information may be found that may prove valuable to those engaged in kindred lines of investigation.

My first investigations were confined to the magnetic declination, or the variation of the compass, with a view of forming empirical equations, by the method of least squares, for each station at which the extent of the series of observations is sufficient for the purpose, and from them predicting values of the declination for use in assigning the best values of the direction of the magnetic meridian on the nautical charts constructed by the Navy Department for the navigation of the navy and the mercantile marine, and also from their first differentials the yearly rates of change of direction of the compass needle at any time not greatly beyond the limits

of the period of observation. With the increasing importance of a knowledge of the magnetic dip or inclination in the navigation of modern vessels of commerce and of war, attention was turned to the deduction from the collected observations of empirical equations representing that element at the various stations with a view of predicting values at these places and of arriving at appropriate methods for bringing forward to the present or some future time the isoclinic lines represented on the magnetic charts for past epochs.

The empirical equations thus deduced are stated in connection with the observations from which they have been formed. In a few cases the conditional equations were expressed as a series of powers of the form $V = A + Bt + Ct^2$; but, in all cases in which the extent of the series of observed values was sufficient, a harmonic function with an assumed period of the cycle was employed in the following form: $V = A + B\, sin\, \frac{360°}{m} t + C\, cos\, \frac{360°}{m} t$, in which V represents the declination or the inclination, m the period of the cycle, t the time in years and fractions of a year reckoned from some assumed epoch, and A, B, and C constants that are determined from the observations by the method of least squares.

It may be useful to make it known that my later work in the deduction of these equations was facilitated by finding the correction to the assumed period, which was necessary to bring about a reasonable accord between the observed values and those computed from the deduced equations for the corresponding times, instead of assuming several values of the period and, after performing all the work of deduction for each, selecting that which gave the most accordant set of computed values or the smallest probable error of a single observation.

The most vital objection to the method first followed is that there is no ready means of ascertaining when the best empirical equation that the observations will yield has been obtained.

Having found an approximate empirical equation with an assumed value of the period of the cycle and computed a table of differences between the observed and computed values, I differentiated the equation and obtained one of the form:

$$dI = dA + \sin\frac{360^\circ}{m}t.\,dB + \cos\frac{360^\circ}{m}t.\,dC$$

$$-\frac{360}{m^2}\left(B\cos\frac{360^\circ}{m}t - C\sin\frac{360^\circ}{m}t\right)dm,$$

in which m represents the assumed period, t the interval of time of observation from an assumed epoch, and A, B, and C the constants of the approximate empirical equation.

A series of conditional equations were then formed by putting for dI the successive differences between the observed and the corresponding computed values from the approximate equation and the corrections dA, dB, dC, and dm to the constants of the empirical equation were then found by the method of least squares.

The present work is devoted largely to the southern hemisphere, with reference to which I am not aware that any similar extensive investigations have been made, and its field is altogether outside of the United States and Europe, concerning which data have been made abundant by the observatories and by the labors of Mr. Charles A. Schott, Mr. Louis A. Bauer, and Mr. Henry Gannett.

Having accomplished my object with reference to the separate use of the investigations concerning the declination and the inclination in their practical bearing upon navigation, I have endeavored to support the general effort of the geomagneticians of the day by putting the available data relating to the secular change of the earth's magnetism in the form already employed by Bauer,* Schott,† and my-

* Beiträge zur Kenntniss des Wesens der Säcular-Variation des Erdmagnetismus, von Louis A. Bauer. Berlin, 1895.

† Secular Variation of the Earth's Magnetic Force in the United States and in some Adjacent Foreign Countries, by Charles A. Schott. Appendix No. 1, U. S. Coast and Geodetic Survey Report for 1895.

self* to portray the secular course of a freely suspended magnet, and thus, by providing homogeneous data concerning all parts of the world, to contribute toward an advance of our information to such a stage as to make the study of the causes of the secular change in the earth's magnetic state a feasible undertaking.

A freely suspended magnet is observed to be in a state of continuous tremulous motion of an involved character, which may be resolved into irregular and periodic. The irregular motions comprise those sudden and rapid fluctuations in the direction of the needle which can not be predicted. The periodic motions are the solar variations, which include the solar-diurnal variation, depending upon the hour of the day; the annual variation, depending upon the day of the year, and the solar-synodic variation, depending upon the synodic revolution of the sun; the lunar variations, depending upon the moon's hour-angle and her other elements of position and partaking of the character of the tides, and the decennial variations, which may depend upon the frequency and magnitude of the solar spots. Both the irregular and periodic motions referred to are of such small amplitude in all except the polar regions of the earth that they do not affect any of the practical uses of the magnetic needle on the sea; but besides these there is another motion, having an amplitude reaching 30° or 40° in some parts of the world, which is also supposed to be of periodic character, and which is doubtless of radical importance in meteorological science and in the use of the compass in modern navigation.

At a particular instant of time the lines of magnetic force at any place to which a freely suspended magnet will set itself tangent will have a certain direction and strength. The angle between the plane of the astronomical meridian

* (*a*) Contributions to Terrestrial Magnetism. U. S. Hydrographic Office Publication No. 109*a*, 1895.

(*b*) Contributions to Terrestrial Magnetism. U. S. Hydrographic Office Publication No. 114, 1897.

(*c*) Terrestrial Magnetism, vol. I, No. 2, 1896.

and the vertical plane passing through the magnet, or through the line of force, is the magnetic declination, or the variation of the compass; the angle between the horizon and the direction of the needle, measured in the vertical plane passing through it, is the dip or inclination; and the force with which the needle is held in the direction of the lines of force is called the magnetic intensity. The declination and inclination, or the directional elements, which alone are concerned in a discussion of the direction of the magnetic field, have generally been treated separately in investigating the secular change of the magnetic needle. From 1634, when the fact of the secular variation of the declination was established, and from 1576, when the inclination or dip was discovered, reliable observations of these respective elements are recorded for the great populous centers of Europe, and soon observations of the declination or variation of the compass, a knowledge of which is necessary to mariners in the navigation of their ships, had been made by navigators in most of the known parts of the world. Although the older observations, having been made without the means of precise measurement, are subject to a probable error of as much as 1°, they can be accepted as serviceable in the discussion of long series, and serve to reveal satisfactorily the secular change of the declination. Through the results of the observations of the navigators of successive periods, series of observations of the declination extending over two or three centuries are available for most of the important maritime stations of the world. An examination of the curves resulting from platting the observed and computed values of the declination at a few stations, where the series extend over the greatest duration and are the most complete, will show upon what evidence rests the widespread belief that the secular variation of the magnetic declination is a periodic phenomenon.

There are also available for discussion series of observations of the dip or magnetic inclination ranging from one hundred to three hundred years in duration, but the stations are not so numerous nor the observations so complete as in

the case of the declination, except in the long-settled regions of European civilization. This is accounted for by the fact that the dip was rarely observed by navigators, except when employed in expeditions of scientific research, while the declination was found as a necessary performance in the navigation of their ships. The investigation of the long series has led to the belief that the secular variation of the inclination is also a periodic phenomenon. But the data which have been observed up to the present are manifestly insufficient to warrant a conclusion that after a certain period has elapsed the declination at any given station will be the same as it is now, and will then repeat its changes and again assume the same value after the lapse of the same interval of time, or that the inclination at that place will be found to pass through a cycle of changes and return to the same value at regular intervals of time. While the separate investigation of series of observations of declination and inclination is of practical usefulness in gaining a knowledge of the rate of secular change of these elements and predicting values beyond the range of the observations, in seeking to discover the causes of the secular change in the direction of the magnetic needle and to establish or disprove its periodic character, the declination and inclination should be viewed as component effects of the forces that are acting. Such a view brings us to the investigation of the successive directions in space assumed at successive epochs by a freely suspended magnet or the consideration of the observed values of the declination and inclination conjointly, instead of the separate consideration of values of the direction of the compass needle and of the dipping needle. As a freely suspended magnet assumes its successive directions for different times, it describes a conical surface whose vertex is the center of gravity of the needle.

If a sphere of any convenient radius be described, with its center coinciding with the center of gravity of the needle, and the conical surface be extended through the surface of the

sphere, the line of intersection will be a serpentine curve which represents the actual secular motion of the needle.

At the present time we know, with moderate accuracy, the values of the three magnetic elements for the inhabited portions of the world, and also, with a lesser accuracy, the rates of secular change in the elements; but we have no knowledge as to whether the needle, when it points in a certain direction at a given place, will ever return to the same position again, or whether it will at the end of a certain period assume the same direction, and again sweep over the same path in the same period. Nor do we know that the secular-variation period, if there shall hereafter be found to be one, will be the same in all parts of the world.

Following the observations and results for the different stations is a condensed statement of the empirical equations for declination and inclination and of the decennial values of both elements from which the curves of the secular motion of the needle have been traced in each case upon a gnomonic projection of a globe twelve inches in radius, whose point of tangency has for its latitude the mean of the extreme values of the inclination during the epoch for which the curve is constructed, and for its longitude the mean of the extreme declinations.

Lat. 18° 28′ S. **ARICA, PERU.** Long. 70° 20½′ W.

Year.	Magnetic declination.	Authority. Observer.	Where recorded.
	°		
1713........	— 8.00	....	Brewster's Treatise on Mag., Edinb., 1834.
1821........	—10.42	B. Hall..................................	Becquerel's Traité du Magnetisme.
1827........	—10.75	....	Sabine's Collection, Phil. Trans. Royal Society, 1877.
1835........	—11.00	....	
1858........	—10.88	....	
1883........	—10.00	Ensign Favereau, Fr. N......	Annales Hydrographiques, 2d series, 1884.
1893........	— 9.87	Lieut. Mottez, Fr. N............	Annales Hydrographiques, 2d vol., 1893.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1713........	— 8.00	— 8.026	+0.03	0.0009	Probable error of single observation = ± 06′. Period = 240 years.
1821........	—10.42	—10.581	+0.16	0.0256	
1827........	—10.75	—10.692	—0.06	0.0036	
1835........	—11.00	—10.793	—0.21	0.0441	
1858........	—10.88	—10.738	—0.14	0.0196	
1883........	—10.00	—10.072	+0.07	0.0049	
1893........	— 9.87	— 9.808	—0.06	0.0036	
				0.1023	

Empirical equation for finding the declination for any year: $v = -9^\circ.4 + 0.223 \sin 1.5\,(t - 1850) - 14.61 \cos 1.5\,(t - 1850)$.

Lat. 7° 55.5′ S. ASCENSION ISLAND. Long. 14° 24′ W.

Year.	Magnetic declination.	Authority. Observer.	Where recorded.
	°		
1700	—2.00		Halley, in his Tabula Nautica, etc.
1754.3	8.10	De la Caille	Hansteen's Magnetismus der Erde, Christiana, 1819.
1768.25	9.88	Wallis	Do.
1775.4	10.87	Cook	Do.
1806.3	15.67	Bonsoe	Do.
1816	15.50	Brine	Becquerel's Traité du Magnetisme.
1825	16.87	Duperrey	Do.
1830*	20.16	Foster	Phil. Trans. Royal Society, Part II, 1877.
1836	17.60	Fitz Roy	Do.
1839	18.52	Du Petit Thouars	Do.
1842	19.27	Belcher	Do.
1846	19.27	Bérard	Do.
1861	21.75	Denham	Do.
1863	21.63	H. M. S. Hecate	Do.
1876.25	22.77 { 23.10, 22.53, 22.68	Nares and Thomson, R.N.	Report of Voyage of H. M. S. Challenger.
1890.3	23.00 { 22.6, 23.4	E. D. Preston, assistant, United States Coast and Geodetic Survey.	Bulletin No. 23, United States Coast and Geodetic Survey, March, 1891.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1700	—2.00	—2.47	+0.47	0.2209	
1754.3	8.10	7.68	+0.42	0.1764	
1768.25	9.88	9.66	+0.22	0.0484	
1775.4	10.87	10.66	+0.21	0.0441	
1806.3	15.67	14.93	+0.74	0.5476	
1816	15.50	16.15	+0.35	0.1175	
1825	16.87	17.23	—0.36	0.1296	
1836	17.60	18.62	—1.02	1.0404	Probable error of a single observation = ± 21.6′. Period = 600 years.
1839	18.52	18.95	—0.43	0.1849	
1842	19.27	19.27	0.00	0.0000	
1846	19.27	19.70	—0.43	0.1849	
1861	21.75	21.13	+0.62	0.3844	
1863	21.63	21.31	+0.32	0.1024	
1876.25	22.77	22.32	+0.45	0.2025	
1890.3	23.00	23.15	—0.15	0.0225	
				3.4065	

(* Omitted in investigation.)

Empirical equation for determining the declination for any year: $v = 10°.55 + 9.47 \sin 0.6 (t - 1850) + 9.56 \cos 0.6 (t - 1850)$.

Lat. 13° 05′ N. BARBADOS (BRIDGETOWN). Long. 59° 37′ W.

Year.	Magnetic declination.	Authority.	
		Observer.	Where recorded.
	°		
1726	—3.91	Mathews	Encyclopædia Metropolitana, London, 1848.
1760	—4.50	Ross	Do.
1761	—3.78	..... do	Do.
1833	—1.48	Philips	Phil. Trans. Royal Society, 1875.
1839	—1.22	Milne	Do.
1846	—1.45	Schomburgk	Do.
1882	0.42		British Admiralty Chart.
1888	1.03	Lieut. F. H. Delano, U. S. N.	Hydrographic Office, archive document.
1890.4	1.30	E. D. Preston, assistant, United States Coast and Geodetic Survey.	Bulletin No. 23, United States Coast and Geodetic Survey.
1892	0.80	Lieut. W. W. Kimball, U.S.N.	Hydrographic Office, archive document.
1893	1.28	......do	Do.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1726	—3.91	—3.59	—0.32	0.1024	Probable error of a single observation = ± 15′. Period = 300 years.
1760	—4.50	—4.29	—0.21	0.0441	
1761	—3.78	—4.29	+0.51	0.2601	
1833	—1.48	—1.70	+0.22	0.0484	
1839	—1.22	—1.35	+0.13	0.0169	
1846	—1.45	—0.95	—0.50	0.2500	
1882	+0.42	+0.73	—0.31	0.0961	
1888	+1.03	+0.90	+0.13	0.0169	
1890.4	+1.30	+0.96	+0.34	0.1156	
1892	+0.80	+0.99	—0.19	0.0361	
1893	+1.28	+1.02	+0.26	0.0676	
				1.0542	

Empirical equation for finding the declination for any year: $v = -1°.54 + 2.62 \sin 1.2 (t - 1850) + 0.812 \cos 1.2 (t - 1850)$.

Lat. 6° 08′ S. BATAVIA, JAVA. Long. 106° 48′ E.

Year.	Magnetic declination.	Authority. Observer.	Where recorded.
	°		
1605	+3.33		
1609	+3.00	Saris	Hansteen's Magnetismus der Erde, Christiana, 1819.
1767	+1.42	Wallis	Do.
1814	—0.28	B. Hall	Becquerel's Traité du Magnetisme.
1828	—0.52	Blosseville	Phil. Trans. Royal Society, Part II, 1877.
1846	—0.88	Elliot	Do.
1858	—1.08	Novara Expedition	Do.
1876.5	—1.70	van Rijckevorsel	Published by Royal Academy of Sciences, Amsterdam.
1882.75	—1.93	van Stock	Magnetical and meteorological observations at the Batavian Observatory, Vols. VI and VII.
1883.5	—1.93		
1884	—1.91		
1885	—1.89		

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1605	+3.33	+2.94	+0.39	0.1521	Probable error of a single observation = ± 15′. Period = 400 years.
1609	+3.00	+3.12	—0.12	0.0144	
1767	+1.42	+1.87	—0.45	0.2025	
1814	—0.28	—0.34	+0.06	0.0036	
1828	—0.52	—0.86	+0.34	0.1156	
1846	—0.88	—1.35	+0.47	0.2209	
1858	—1.08	—1.56	+0.48	0.2304	
1876.5	—1.70	—1.67	—0.03	0.0009	
1882.75	—1.93	—1.64	—0.29	0.0841	
1883.5	—1.93	—1.64	—0.29	0.0841	
1884	—1.91	—1.63	—0.28	0.0784	
1885	—1.89	—1.63	—0.26	0.0676	
				1.2546	

Empirical equation for finding the declination for any year: $v = 1^\circ.494 - 1.194 \sin 0.9\,(t - 1850) - 2.928 \cos 0.9\,(t - 1850)$.

Lat. 18° 56′ N. BOMBAY. Long. 72° 54′ E.

Year.	Magnetic declination.	Authority. Observer.	Authority. Where recorded.
	°		
1722	+5.00	Mathews	Encyclopædia Metropolitana, London, 1848.
1817	—0.00	Yates	Do.
1845	+0.22	Orlebar	Phil. Trans. Royal Society, Part I, 1875.
1847	—0.23	Montrion	Do.
1849	—0.25	F. A. E. Keller, Fr. Hydr. Engr.	Annales Hydrographiques, 1851.
1856	—0.32	Schlagintweit	Phil. Trans. Royal Society, Part I, 1875.
1867	—0.70	Chambers	Do.
1872	—0.85	—0.83, Chambers, 1871; —0.86, Chambers, 1872; —0.88, Chambers, 1873	Bombay magnetic and meteorological observations, 1871–'78.
1875	—0.90	—0.89, Chambers, 1874; —0.90, Chambers, 1875; —0.91, Chambers, 1876	Do.
1878	—0.93	—0.925, Chambers, 1877; —0.933, Chambers, 1878	Do.
1881	—0.93	Chambers	Do.
1888.5	—0.82	—0.83, John Dover, 1888; —0.80, John Dover, 1889	Do.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1722	+5.00	+4.92	+0.08	0.0064	
1817	+0.00	+0.63	—0.63	0.3969	
1845	+0.22	—0.29	+0.51	0.2601	
1847	—0.23	—0.34	+0.11	0.0121	
1849	—0.25	—0.39	+0.14	0.0196	
1856	—0.36	—0.54	+0.22	0.0484	Probable error of a single observation = ± 12′.
1867	—0.70	—0.71	+0.01	0.0001	Period = 450 years.
1872	—0.85	—0.76	—0.09	0.0081	
1875	—0.90	—0.78	—0.12	0.0144	
1878	—0.93	—0.80	—0.13	0.0169	
1881	—0.93	—0.81	—0.12	0.0144	
1888.5	—0.82	—0.81	—0.01	0.0001	
				0.7975	

Empirical equation for determining the declination for any year: $v = 2°.665 - 1.625 \sin 0.8 (t - 1850) - 3.08 \cos 0.8 (t - 1850)$.

Lat. 12° 04′ S. CALLAO, PERU. Long. 77° 08′ W.

Year.	Magnetic declination.	Authority. Observer.	Authority. Where recorded.
	°		
1709.9	— 6.25	Feuillée..............................	Hansteen's Magnetismus der Erde, Christiana, 1819.
1802........	— 9.83	....	Becquerel's Traité du Magnetisme.
1823........	— 9.50	....	Voyages of the Adventure and Beagle, 1826–1836, London, 1839.
1827........	—10.66		
1835........	—10.60		
1836.... ...	—10.40	....	Phil. Trans. Royal Society, 1877.
1838........	—10.50		
1858........	—10.66	Friesach..............................	Phil. Trans. Royal Society, Part II, 1877.
1866........	—10.50	....	Phil. Trans. Royal Society, 1877.
1883........	— 9.97	Ensign Favereau, Fr. N....	Annales Hydrographiques, 2d series, 1884.
1892........	—10.00	Lieut. W. P. Conway, U.S.N.	Hydrographic information from U.S.S. Yorktown.
1893........	—10.00	Lieut. L. Mottez, Fr. N......	Annales Hydrographiques, 2d vol., 1893.

Year.	Observed.	Computed.	O-C.	$\overline{O-C}^2$.	
	°	°			
1709.9	— 6.25	— 6.32	+0.07	0.0049	
1802........	— 9.83	— 9.52	—0.31	0.0961	
1823........	— 9.50	—10.21	+0.71	0.5041	
1827........	—10.66	—10.31	—0.35	0.1225	
1835........	—10.60	—10.47	—0.13	0.0169	
1836........	—10.40	—10.49	+0.09	0.0081	Probable error of a single observation = ± 12.25′.
1838........	—10.50	—10.59	+0.01	0.0001	Period = 300 years.
1858........	—10.66	—10.60	—0.06	0.0036	
1866........	—10.50	—10.53	+0.03	0.0009	
1883........	— 9.97	—10.19	+0.22	0.0484	
1892........	—10.00	— 9.91	—0.09	0.0081	
1893........	—10.00	— 9.87	—0.13	0.0169	
				0.8306	

Empirical equation for finding the declination for any year: $v = -8°.45 - 0.105 \sin 1.2\,(t - 1850) - 2.16 \cos 1.2\,(t - 1850)$.

Lat. 33° 56′ S. CAPE OF GOOD HOPE. Long. 18° 29′ E.

Year.	Magnetic declination.	Authority. Observer.	Where recorded.
	°		
1605........	— 0.50	Davis........	Voyages of the Adventure and Beagle.
1609.5	+ 0.20	Keeling........	Do.
1622.5	+ 2.00		
1675.5	+ 8.23	....	Walker's Terrestrial and Cosmical Magnetism.
1691.5	+11.00		
1700........	+10.25	Edm. Halley........	Tabula Nautica, etc.
1751.5	+19.25		
1775.5	+21.23	Wales........	Voyages of the Adventure and Beagle.
1788.5	+24.08		
1792.5	+24.52	Edm. Halley........	Tabula Nautica, etc.
1818.5	+26.52		
1836.5	+28.50	Fitz Roy........	Becquerel's Traité du Magnetisme.
1839.5	+29.15	Edm. Halley........	Tabula Nautica, etc.
1841.5	+29.10		
1842.5	+29.10		
1843.5	+29.10		
1844.5	+29.10		
1845.5	+29.12		
1846.5	+29.14	Observatory........	Reports of observations at Cape of Good Hope Observatory, on file (1888) in library of United States Naval Observatory, Washington, D. C.
1847.5	+29.21		
1848.5	+29.23		
1849.5	+29.27		
1850.5	+29.31		
1857.5	+29.57		
1873.9	+30.07	Capts. Nares and Thomson, R. N.	Voyage of H. M. S. Challenger.
1890.1	+29.53	E. D. Preston, assistant, United States Coast and Geodetic Survey.	Bulletin No. 23, United States Coast and Geodetic Survey.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1605........	— 0.50	+ 0.41	—0.91	0.8281	
1609.5	+ 0.20	+ 0.62	—0.42	0.1764	
1622.5	+ 2.00	+ 1.50	+0.50	0.2500	
1675.5	+ 8.23	+ 7.43	+0.80	0.6400	
1691.5	+11.00	+ 9.74	+1.26	1.5876	
1700........	+10.25	+11.00	—0.75	0.5625	
1751.5	+19.25	+19.16	+0.09	0.0081	
1775.5	+21.23	+22.64	—1.41	1.9881	
1788.5	+24.08	+24.31	—0.23	0.0529	
1792.5	+24.52	+24.79	—0.27	0.0729	
1818.5	+26.52	+27.43	—0.91	0.8281	
1836.5	+28.50	+28.69	—0.19	0.0361	
1839.5	+29.15	+28.84	+0.31	0.0961	Probable error of a single observation = ± 22.5′.
1841.5	+29.10	+28.94	+0.16	0.0256	Period = 590 years.
1842.5	+29.10	+28.99	+0.11	0.0121	
1843.5	+29.10	+29.03	+0.01	0.0049	
1844.5	+29.10	+29.08	+0.02	0.0004	
1845.5	+29.12	+29.12	0.00	0.0000	
1846.5	+29.14	+29.18	—0.04	0.0016	
1847.5	+29.21	+29.20	+0.01	0.0001	
1848.5	+29.23	+29.24	—0.01	0.0001	
1849.5	+29.27	+29.27	0.00	0.0000	
1850.5	+29.31	+29.30	+0.01	0.0001	
1857.5	+29.57	+29.50	+0.07	0.0049	
1873.9	+30.07	+29.62	+0.45	0.2025	
1890.1	+29.53	+29.29	+0.24	0.0576	
				7.4368	

Empirical equation for determining the declination for any year: $v = 14°.63 + 3.178 \sin 0.61 (t - 1850) + 14.659 \cos 0.61 (t - 1850)$.

Lat. 19° 26′ N. CITY OF MEXICO. Long. 99° 05′ W.

Year.	Magnetic declination.	Authority.	
		Observer.	Where recorded.
	°		
1769	—5.47	Don Alzate	Hansteen's Magnetismus der Erde, 1819.
1775	—6.70	Velasques de Leon	Mem. del Observatorio Met. Central de Mexico, 1880.
1803	—8.13	Humboldt	Hansteen's Magnetismus der Erde, 1819.
1849	—8.50	Gomez de la Cortina	Mem. del Observatorio Met. Central de Mexico, 1880.
1850	—8.59	Velasques and Teran	Tratado de Topografia y Geodesia, Mexico, 1869.
1856	—8.77	Müller and Sontag	Phil. Trans. Royal Society, 1875.
1858	—8.37	Salazar Illaregui	Tratado de Topografia y Geodesia, Mexico, 1869.
1860	—8.50	Diaz Covarubias	Do.
1862	—8.45	Iglesias	Mem. del Observatorio Met. Central de Mexico, 1880.
1866.5	—8.14	Ponce de Leon	Tratado de Topografia y Geodesia, Mexico, 1869.
1868	—8.17	Fernandez	Do.
1879	—8.58		Mem. del Observatorio Met. Central de Mexico, 1880.
1885.3	—8.31		

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1769	—5.47	—6.03	+0.56	0.314	
1775	—6.70	—6.35	—0.35	0.123	
1803	—8.13	—7.65	—0.48	0.230	
1849	—8.50	—8.60	+0.10	0.010	
1850	—8.59	—8.61	—0.02	0.000	
1856	—8.77	—8.59	—0.18	0.032	Probable error of a single observation = ± 14′.
1858	—8.37	—8.58	+0.21	0.044	Period = 360 years.
1860	—8.50	—8.56	+0.06	0.004	
1862	—8.45	—8.53	+0.08	0.006	
1866.5	—8.14	—8.47	+0.33	0.109	
1868	—8.17	—8.45	+0.28	0.078	
1879	—8.58	—8.21	—0.37	0.137	
1885.3	—8.31	—8.03	—0.28	0.078	
				1.165	

Empirical equation for the determination of the declination for any year: $v = -5°.52 + 0.027 \sin (t - 1850) - 3.09 \cos (t - 1850)$.

Lat. 36° 42′ S. CONCEPCION. Long. 73° 07′ W.

Year.	Magnetic declination.	Authority.	
		Observer.	Where recorded.
	°		
1709........	—10.33	Feuillée..............................	Hansteen's Magnetismus der Erde, Christiana, 1819.
1792........	—14.86	}	Brewster's Treatise on Magnetism, Edinburg, 1834.
1794........	—14.86		
1821........	—15.50	B. Hall....................	Becquerel's Traité du Magnetisme.
1823........	—16.27	Duperrey..........	Voyage autour du Monde, Paris, 1829.
1824........	—15.00	Kotzebue	Phil. Trans. Royal Society, 1877.
1825........	—16.82	Beechey.............................	
1826........	—16.79	Fitz Roy.............................	
1827........	—17.03	Lütke	
1829........	—16.79	King..................................	
1835........	—16.80	Fitz Roy.............................	
1882........	—17.23	Lieuts. Barnardières and Barnaud, Fr. N.	Annales Hydrographiques, 1884.
1893........	—16.75	Lieut. Mottez, Fr. N............	Annales Hydrographiques, 2d vol., 1893.

Year.	Observed.	Computed.	O-C.	$\overline{O-C}^2$.	
	°	°			
1709........	—10.33	—10.45	+0.12	0.0144	Probable error of single observation = ± 23.22′. Period = 360 years.
1792........	—14.86	—14.74	—0.12	0.0144	
1794........	—14.86	—14.85	—0.01	0.0001	
1821........	—15.50	—16.25	+0.75	0.5625	
1823........	—16.27	—16.30	+0.03	0.0009	
1824........	—15.00	—16.34	+1.34	1.7956	
1825........	—16.82	—16.37	—0.45	0.2025	
1826........	—16.79	—16.41	—0.38	0.1444	
1827........	—17.03	—16.45	—0.58	0.3364	
1829........	—16.79	—16.54	—0.25	0.0625	
1835........	—16.80	—16.72	—0.08	0.0064	
1882........	—17.23	—16.97	—0.26	0.0676	
1893........	—16.75	—16.70	—0.05	0.0025	
				3.2102	

Empirical formula for determining the declination for any year: $v = -13°.626 - 0.829 \sin(t - 1850) - 3.424 \cos(t - 1850)$.

Lat. 29° 57′ S. COQUIMBO. Long. 71° 22′ W.

Year.	Magnetic declination.	Authority.	
		Observer.	Where recorded.
	°		
1700	— 8.53	Feuillée	Hansteen's Magnetismus der Erde, Christiana, 1819.
1712	—10.00	}	Brewster's Treatise on Magnetism, Edinburg, 1834.
1791.3	—11.77	}	Brewster's Treatise on Magnetism, Edinburg, 1834.
1821	—14.00	B. Hall	Becquerel's Traité du Magnetisme.
1828	—14.40	Beechey	Phil. Trans. Royal Society, Part II, 1877.
1834	—14.40	Fitz Roy	Voyages of Adventure and Beagle, London, 1839.
1853	—14.59	}	French Chart No. 1746.
1870	—14.67	}	French Chart No. 1746.
1882	—14.35	Ensign Favereau, Fr. N.	Annales Hydrographiques, 2d series, 1884.
1883	—13.70	Lieut. F. Hanford, U. S. N.	Naval Professional Papers, No. 19.
1889	—13.59	Chilean astronomers	Chilean Hydrographic Notices, No. 12, 1890.
1891	—13.63	Lieut. J. F. Moser, U. S. N., U. S. S. San Francisco.	Contributions to Terrestrial Magnetism, Hydrographic Office Publication, No. 109.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1700	— 8.53	— 8.97	+0.44	0.1936	
1712	—10.00	— 9.27	—0.77	0.5929	
1791.3	—11.77	—12.77	+1.00	1.0000	
1821	—14.00	—13.88	—0.12	0.0144	
1828	—14.40	—14.06	—0.34	0.1156	
1834	—14.40	—14.18	—0.22	0.0484	Probable error of a single observation = ± 21.3′.
1853	—14.59	—14.39	—0.20	0.0400	Period = 360 years.
1870	—14.67	—14.30	—0.37	0.1369	
1882	—14.35	—14.09	—0.26	0.0676	
1883	—13.70	—14.06	+0.36	0.1296	
1889	—13.59	—13.92	+0.33	0.1089	
1891	—13.63	—13.86	+0.23	0.0529	
				2.5008	

Empirical formula for determining the declination for any year: $v = -11°.55 - 0.281 \sin (t - 1850) - 2.82 \cos (t - 1850)$.

Lat. 38° 32′ N. FAYAL, AZORES. Long. 28° 33′ W.

Year.	Magnetic declination.	Authority.	
		Observer.	Where recorded.
	°		
1589.7	—3.09	Wright	Hansteen's Magnetismus der Erde, Christiana, 1819.
1775.5	22.12	Cook	Do.
1814........	23.50	Reid	Becquerel's Traité du Magnetisme.
1829........	25.92	Lütke	Phil. Trans. Royal Society, Part I, 1875.
1842........	27.00	Vidal	Do.
1890........	25.87	Lieut. J. C. Colwell, U. S. N.	Hydrographic Office Publication, No. 109.
1891........	24.50	H. M. S. Acorn	Letter from the British hydrographer, dated May 11, 1893.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1589.7	—3.09	—2.92	—0.17	0.0289	Probable error of a single observation = ± 46′. Period = 530 years.
1775.5	22.12	21.03	+1.09	1.1881	
1814........	23.50	25.17	—1.67	2.7889	
1829........	25.92	26.04	—0.12	0.0144	
1842........	27.00	26.49	+0.51	0.2601	
1890........	25.87	25.06	+0.81	0.6561	
1891........	24.50	24.97	—0.47	0.2209	
				5.1574	

Empirical equation to determine the declination for any year: $v = 11°.82 + 0.23 \sin \frac{36}{53}(t - 1850) + 14.75 \cos \frac{36}{53}(t - 1850)$.

Lat. 23° 09′ N. HABANA, CUBA. Long. 82° 22′ W.

Year.	Magnetic declination.	Authority. Observer.	Authority. Where recorded.
	°		
1726	—4.40	Mathews	Encyclopædia Metropolitana, 1848.
1732.3	—4.50	Harris	Do.
1815	—7.00		Encyclopædia Britannica, 7th ed., 1842.
1816.5	—5.50	Bentley	Do.
1840	—5.67	Lavallée	Becquerel's Traité du Magnetisme.
1857	—5.27	United States Coast Survey; Friesach	Sabine's Collection, Phil. Trans. Royal Society, 1875.
1858	—5.75		From a map of Cuba, 1860.
1874.5	—4.28	Benito Viñes	Observaciones Magneticas y Meteorologicas de Real Colegio de Belen, 1st semestre, 1876.
1879.2	—3.90	Lieut. Com. Ackley, U.S.N.	Hydrographic Office archives document.
1885.3	—3.68	Benito Viñes	Observaciones Magneticas y Meteorologicas de Real Colegio de Belen.
1887	—3.62	do	Do.
1888.3	—3.61	do	Do.
1889.3	—3.57	do	Do.

Year.	Observed.	Computed.	O-C.	$\overline{O-C}^2$.	
	°	°			
1726	—4.40	—4.22	—0.18	0.0324	
1732.3	—4.50	—4.55	+0.05	0.0025	
1815	—7.00	—6.47	—0.53	0.2809	
1816.5	—5.50	—6.54	+1.04	1.0816	
1840	—5.67	—5.87	+0.20	0.0400	
1857	—5.27	—5.19	—0.08	0.0064	
1858	—5.75	—5.14	—0.61	0.3721	Probable error of a single observed value = ± 17′. Period = 360 years.
1874.5	—4.28	—4.32	+0.04	0.0016	
1879.2	—3.90	—4.08	+0.18	0.0324	
1885.3	—3.68	—3.98	+0.30	0.0900	
1887	—3.62	—3.65	+0.03	0.0009	
1888.3	—3.61	—3.59	—0.02	0.0004	
1889.3	—3.57	—3.53	—0.04	0.0016	
				1.9428	

Empirical equation for determining the declination for any year: $v = -3^{\circ}.42 + 2.36 \sin (t - 1850) - 2.07 \cos (t - 1850)$.

Lat. 22° 16′ N. HONGKONG, CHINA. Long. 114° 10′ E.

Year.	Magnetic declination.	Authority.	
		Observer.	Where recorded.
	°		
1780	+0.50	Cook	Hansteen's Magnetismus der Erde, Christiana, 1819.
1792	—1.28		Brewster's Treatise on Magnetism, Edinburg, 1837.
1824	—1.70	Bougainville	Becquerel's Traité du Magnetisme.
1827	—2.00	Beechey	Phil. Trans. Royal Society, Part I, 1875.
1830	—1.58	Laplace	Do.
1837	—1.08	Darandeau	Do.
1843	—0.62	Belcher	Do.
1855	—0.50	Richards	Observations and Researches at Hongkong, by W. Doberck.
1875	—0.93	Richards	Observations and Researches at Hongkong, by W. Doberck.
1876	—0.60		Annales Hydrographiques, 1876.
1884	—0.77		Observations and Researches made at Hongkong, by W. Doberck.
1885.5	—0.75		Observations and Researches made at Hongkong, by W. Doberck.
1887.5	—0.70	Doberck	Hongkong, Government Gazette, May 31, 1888.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	Wts.		
	°	°					
1780	+0.50	−0.48	+0.98	0.9604	¼	0.2401	Probable error of a single observation = ± 15′. Period = 450 years.
1792	—1.28	—0.70	—0.58	0.3364	¼	0.0841	
1824	—1.70	—1.06	—0.64	0.4096	½	0.2048	
1827	—2.00	—1.08	—0.92	0.8464	¼	0.2116	
1830	—1.58	—1.08	—0.50	0.2500	½	0.1250	
1837	—1.08	—1.09	+0.01	0.0001	½	0.0001	
1843	—0.62	—1.08	+0.46	0.2116	1	0.2116	
1855	—0.50	—1.03	+0.53	0.2809	1	0.2809	
1875	—0.93	—0.80	—0.13	0.0169	1	0.0169	
1876	—0.60	—0.79	+0.19	0.0361	1	0.0361	
1884	—0.77	—0.65	—0.12	0.0144	1	0.0144	
1885.5	—0.75	—0.62	—0.13	0.0169	1	0.0169	
1887.5	—0.70	—0.59	—0.11	0.0121	1	0.0121	
						1.4546	

Empirical equation for determining the declination for any year: $v = 0°.990 + 0.389 \sin 0.8\,(t - 1850) - 2.047 \cos 0.8\,(t - 1850)$.

Lat. 21° 18′ N. HONOLULU. Long. 157° 52′ W.

Year.	Magnetic declination.	Authority. Observer.	Where recorded.
	°		
1817	—10.95	Kotzebue	Coast and Geodetic Survey Report, 1882, Appendix No. 12.
1819	—10.40	Freycinet	Do.
1824.5	— 9.87	Byron	Phil. Trans. Royal Society, 1875.
1827	—10.43	Beechey	Do.
1836	—10.18		Voyage de la Bonite, Paris, 1842.
1837	—10.33 {10.00		Voyage de la Venus, Paris, 1841.
	{10.66	Beechey	Phil. Trans. Royal Society, 1875.
1838	—10.65	Belcher	Do.
1840	— 9.28	Berghaus	Coast and Geodetic Survey Report, 1882.
1852	— 9.17	Collinson	Phil. Trans. Royal Society, 1875.
1859.2	— 9.68	Friesach	Memoirs of the Imperial Academy of Sciences, Vienna, vols. XXIX to XLIV.
1871	— 9.60	Lyon	Hawaiian Government Survey.
1872	— 9.30	do	Do.
1875	— 9.27	Alexander	Do.
1875.5	— 9.35	Capts. Nares and Thomson, R. N.	Voyage of H. M. S. Challenger.
1879	— 9.53	Lyon	Coast and Geodetic Survey Report, 1888, Appendix No. 7.
1881	— 9.67	do	Do.
1884	—10.23	do	Do.
1888.2	—10.05	Lieut. J. C. Wilson, U. S. N.	Hydrographic Office archives document.
1891.2	—10.20	Lyon	Communicated in letter to author, Feb. 16, 1891.
1892.5	—10.27	E. D. Preston	Coast and Geodetic Survey Report for 1893, part 2.
1894.9	—10.33	Lyon	Hydrographic Office archives document.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1817	—10.95	—10.85	—0.10	0.0100	
1819	—10.40	—10.72	+0.32	0.1024	
1824.5	— 9.87	—10.40	+0.53	0.2809	
1827	—10.43	—10.27	—0.16	0.0256	
1836	—10.18	— 9.88	—0.30	0.0900	
1837	—10.33	— 9.85	—0.48	0.2304	
1838	—10.65	— 9.82	—0.83	0.6889	
1840	— 9.28	— 9.75	+0.47	0.2209	
1852	— 9.17	— 9.49	+0.32	0.1024	
1859.2	— 9.68	— 9.43	—0.25	0.0625	
1871	— 9.60	— 9.52	—0.08	0.0064	Probable error of a single observation = ± 14′.
1872	— 9.30	— 9.53	+0.23	0.0529	
1875	— 9.27	— 9.59	+0.32	0.1024	
1875.5	— 9.35	— 9.60	+0.25	0.0625	
1879	— 9.53	— 9.68	+0.15	0.0225	
1881	— 9.67	— 9.74	+0.07	0.0049	
1884	—10.23	— 9.83	—0.40	0.1600	
1888.2	—10.05	—10.00	—0.05	0.0025	
1891.2	—10.20	—10.13	—0.07	0.0049	
1892.5	—10.27	—10.19	—0.08	0.0064	
1894.9	—10.33	—10.30	—0.03	0.0009	
				2.2403	

Empirical equation for determining the declination for any year: $v = -9^\circ.52 + 0.0158\,(t - 1850) - 0.00074\,(t - 1850)^2$.

Lat. 24° 38′ N. MAGDALENA BAY, LOWER CALIFORNIA. Long. 112° 07′ W.

Year.	Magnetic declination.	Authority.	
		Observer.	Where recorded.
	°		
1783.3	— 6.78	Spanish navigators...............	Coast and Geodetic Survey Appendix, No. 7, Report for 1888, p. 273.
1837........	— 8.28	La Venus...............................	Phil. Trans. Royal Society, 1875.
1839........	— 9.25	Belcher	Do.
1866.......	—10.68	Harkness..............................	Smithsonian Contributions to Knowledge, No. 239, 1873.
1871.3	—11.00	G. Bradford, assistant, Coast and Geodetic Survey.	Chart in Coast Survey archives.
1873.3	—10.56	W. Eimbeck, assistant, Coast and Geodetic Survey. Commander G. Dewey, U. S. N.	Appendix No. 13, Coast and Geodetic Survey Rep., 1882.
1881.2	—10.48	Lieut. Commander H. E. Nichols, U. S. N.	Coast and Geodetic Survey Appendix, No. 7, Report for 1888, p. 273.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1783.3	— 6.78	— 5.77	—1.01	1.020	Probable error of a single observation = ± 35′. Period = 252 years.
1837........	— 8.28	— 9.54	+1.26	1.588	
1839........	— 9.25	— 9.72	+0.47	0.221	
1866........	—10.68	—10.58	—0.10	0.010	
1871.3	—11.00	—10.59	—0.41	0.168	
1873.3	—10.56	—10.58	+0.02	0.000	
1881.2	—10.48	—10.47	—0.01	0.000	
				3.007	

Empirical equation for determining the declination for any year: $v = -7^\circ.484 - 1.469 \sin \frac{10}{7}(t - 1850) - 2.739 \cos \frac{10}{7}(t - 1850)$.

Lat. 14° 36′ N. MANILA. Long. 120° 58′ E.

Year.	Magnetic declination.	Authority. Observer.	Authority. Where recorded.
	°		
1766	+0.25	Le Gentil	Hansteen's Magnetismus der Erde, Christiana, 1819.
1792.6	—0.29		Brewster's Treatise on Magnetism, Edinburg, 1834.
1829.5	—0.58	Lütke, 1829, 0°.17; Laplace, 1830, 1°	Phil. Trans. Royal Society, Part I, 1875.
1836	—0.50		Voyage de la Bonite, Paris, 1842.
1844	—0.30	Belcher	Phil. Trans. Royal Society, Part I, 1875.
1887	—0.83	Observatory	El Magnetismo Terrestre en Filipinas por P. Ricardo Cirera, S. J.
1887 *	—1.00	U. S. S. Essex	Hydrographic Office archives document.
1890	—0.80	Observatory	Report of Observatorio Meteorologico de Manila, 1890.

Year.	Observed.	Computed.	O-C.	$\overline{O-C}^2$.	Wts.		
	°	°					
1766	+0.25	+0.13	+0.12	0.0144	1	0.0144	Probable error of a single observation = ± 08.3′. Period = 360 years.
1792.6	—0.29	—0.11	—0.18	0.0324	1	0.0324	
1829.5	—0.58	—0.47	—0.11	0.0121	2	0.0242	
1836	—0.50	—0.53	+0.03	0.0009	2	0.0018	
1844	—0.30	—0.60	+0.30	0.0900	1	0.0900	
1887	—0.83	—0.80	—0.03	0.0009	3	0.0027	
1890	—0.80	—0.80	+0.00	0.0000	3	0.0000	
						0.1655	

* Omitted in investigation.

Empirical equation for determining the declination for any year: $v = -0^\circ.223 - 0.399 \sin (t - 1850) - 0.418 \cos (t - 1850)$.

Lat. 34° 54′ S. MONTEVIDEO. Long. 56° 12′ W.

Year.	Magnetic declination.	Authority. Observer.	Authority. Where recorded.
	°		
1789.7	—13.67	....	Brewster's Treatise on Magnetism, Edinburg, 1834.
1807.......	—13.33	Beaufort	Becquerel's Traité du Magnetisme.
1820.......	—12.78	Freycinet	Do.
1826*......	—10.39	Fitz Roy...........	Voyages of the Adventure and Beagle, London, 1839.
1827.......	—12.12	King	Phil. Trans. Royal Society, Part II, 1877.
1829.......	—11.72	D'Orbigny	Do.
1830.......	—11.70	Duperrey...........................	Do.
1834.5	—11.62	Fitz Roy, 1833, —12°.66 ...... La Bonite, 1836, —10°.59.....	Do.
1843.5	—10.70	Sullivan	Do.
1844.6	—10.88	Sullivan	Do.
1852.......	—10.22	Macrae	Do.
1866.......	— 9.35	Harkness	Smithsonian Contributions to Knowledge, No. 239, 1873.
1882.6	— 8.23	Lieuts. Barnaud and Barnardières.	Annales Hydrographiques, 1884.
1883*......	— 7.90	Lieut. H. W. Lyon, U. S. N..	Naval Professional Papers, No. 19.
1888.4	— 7.32	Lieut. Davenport, U. S. N....	Hydrographic Office Publication, No. 109.
1893.2	— 7.62	Lieut. Blocklinger, U.S.N., Jan., 1893, —8.27. Lieut. Mottez, Fr. N., May, 1893, —6.97.	Do. Annales Hydrographiques, 2d vol., 1893.
1894.3	— 7.67	Lieut. J. H. Bull, U. S. N....	Hydrographic Office archives document.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1789.7	—13.67	—14.11	0.44	0.1936	Probable error of a single observation = ± 11.76′. Period = 360 years.
1807........	—13.33	—13.02	—0.31	0.0961	
1820........	—12.78	—12.33	—0.45	0.2025	
1827........	—12.12	—11.91	—0.21	0.0441	
1829........	—11.72	—11.78	+0.06	0.0036	
1830........	—11.70	—11.72	+0.02	0.0004	
1834.5	—11.62	—11.44	—0.18	0.0324	
1843.5	—10.70	—10.84	+0.14	0.0196	
1844.6	—10.88	—10.76	—0.12	0.0144	
1852........	—10.22	—10.27	+0.05	0.0025	
1866........	— 9.35	— 9.32	—0.03	0.0009	
1882.6	— 8.23	— 8.28	+0.05	0.0025	
1888.4	— 7.32	— 7.95	+0.63	0.3969	
1893.2	— 7.62	— 7.70	+0.08	0.0064	
1894.3	— 7.67	— 7.64	—0.03	0.0009	
				1.0168	

* Omitted in investigation.

Empirical equation for determining the declination for any year: $v = -10°.28 + 3.9 \sin (t - 1850) - 0.119 \cos (t - 1850)$.

Lat. 5° 05′ S. PAYTA, PERU. Long. 81° 05.5′ W.

Year.	Magnetic declination.	Authority. Observer.	Authority. Where recorded.
	°		
1821	−9.00	B. Hall	Becquerel's Traité du Magnetisme.
1823.2.	−8.93		Sabine's Collection. Phil. Trans. Royal Society, 1877.
1835	−9.00		
1836	−9.00		
1866	−8.88		
1880	−8.67		B. A. variation chart.
1883	−8.23	Lieut. Barnaud, Fr. N.	Annales Hydrographiques, 2d series, 1884.
1884.1	−8.47	Lieut. J. F. Miller	Hydrographic Office Publication, No. 109, Contributions to Terrestrial Magnetism.
1891.3	−8.80	Lieut. J. F. Moser, U. S. N.	Hydrographic Office archives document.
1892.9	−8.27	Lieut. Mottez, Fr. N.	Annales Hydrographiques, 2d vol., 1893.
1894.2	−7.52	Lieut. Fichbohm, U. S. N.	Hydrographic Office Publication, No. 109, Contributions to Terrestrial Magnetism.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1821	−9.00	−9.11	+0.11	0.0121	Probable error of a single observed value = ± 14.22′. Period = 300 years.
1823.2	−8.93	−9.12	+0.19	0.0361	
1835	−9.00	−9.18	+0.18	0.0324	
1836	−9.00	−8.18	+0.18	0.0324	
1866	−8.88	−8.82	−0.06	0.0036	
1880	−8.67	−8.44	−0.23	0.0529	
1883	−8.23	−8.36	+0.13	0.0169	
1884.1	−8.47	−8.32	−0.15	0.0225	
1891.3	−8.80	−8.08	−0.72	0.5184	
1892.9	−8.27	−8.05	−0.22	0.0484	
1894.2	−7.52	−7.98	+0.46	0.2116	
				0.9873	

Empirical equation for determining the declination for any year: $v = -7°.417 + 0.556 \sin 1.2\,(t - 1850) - 1.67 \cos 1.2\,(t - 1850)$.

Lat. 8° 57′ N. PANAMA. Long. 79° 21′ W.

Year.	Magnetic declination.	Authority.	
		Observer.	Where recorded.
	°		
1775.9	—7.80	....	Encyclopædia Britannica, 7th edition, 1842.
1790.8	—7.80	Don A. Malaspina	Berliner Astronomische Jahrbuch, vol. 53, 1828, p. 188.
1802........	—8.00	....	Encyclopædia Britannica, 7th edition, 1842.
1822........	—7.00	B. Hall	Becquerel's Traité du Magnetisme, 1846.
1837........	—7.00	Belcher..................................	Phil. Trans. Royal Society, 1875.
1849........	—7.01	Emory	Do.
1858........	—6.03	Friesach	Do.
1866.4	—5.90	Harkness......................	Do.
1883.2	—5.03	Lieut. Barnaud, Fr. N.........	Annales Hydrographiques, 2d series, 1884.
1885........	—5.25	Lieut.Commander W. Welch	Hydrographic Office Publication, No. 109, Contributions to Terrestrial Magnetism.

Year.	Observed.	Computed.	O-C.	$\overline{O-C}^2$.	
	°	°			
1775.9	—7.80	—7.60	—0.20	0.0400	
1790.8	—7.80	—7.78	—0.02	0.0004	
1802........	—8.00	—7.90	—0.10	0.0100	
1822........	—7.00	—7.52	+0.52	0.2704	
1837........	—7.00	—6.99	—0.01	0.0001	Probable error of a single observation = ± 13′.
1849	—7.01	—6.48	—0.53	0.2809	Period = 200 years.
1858........	—6.03	—6.10	+0.07	0.0049	
1866.4	—5.90	—5.77	— 0.13	0.0169	
1883.2	—5.03	—5.31	+0.28	0.0784	
1885........	—5.25	—5.27	+0.02	0.0004	
				0.7024	

Empirical equation for determining the declination for any year: $v = -6^\circ.540 + 1.367 \sin 1.8\,(t - 1850) + 0.105 \cos 1.8\,(t - 1850)$.

Lat. 8° 03′ S. PERNAMBUCO. Long. 34° 52′ W.

Year.	Magnetic declination.	Authority.	
		Observer.	Where recorded.
	°		
1815	3.00	Hawett	Becquerel's Traité du Magnetisme.
1819	4.75	Roussin	Do.
1822	4.80	Owen	Do.
1836	5.90	Fitz Roy	Voyages of the Adventure and Beagle, 1826–'36.
1865	11.00	Harkness	Phil. Trans. Royal Society, 1877.
1867	11.00	Admiral Mouchez, Fr. N.	French Chart.
1872	11.50		French Chart, No. 2748, pub. 1868, cor. 1873–'75.
1881	12.91	Dr. van Rijckevorsel and E. Engelenburg.	Magnetic Survey of the Eastern Part of Brazil, published by the Royal Academy of Sciences, Amsterdam, 1890.
1892	14.40	Capt. H. M. Franck	Hydrographic Office archives document.
1894.2	14.50	Lieut. J. C. Cresap, U. S. S. Bennington.	Hydrographic Office Publication, No. 109, Contributions to Terrestrial Magnetism.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1815	3.00	3.60	−0.60	0.3600	Probable error of a single observation = ± 17.4′. Period = 400 years.
1819	4.75	4.10	+0.65	0.4225	
1822	4.80	4.48	+0.32	0.1024	
1836	5.90	6.41	−0.51	0.2601	
1865	11.00	10.67	+0.33	0.1089	
1867	11.00	10.97	+0.03	0.0009	
1872	11.50	11.69	−0.19	0.0361	
1881	12.91	12.94	−0.03	0.0009	
1892	14.40	14.36	+0.04	0.0016	
1894.2	14.50	14.63	−0.13	0.0169	
				1.3103	

Empirical equation for determining the declination for any year: $v = 8^\circ.994 + 9.451 \sin 0.9\,(t - 1850) - 0.539 \cos 0.9\,(t - 1850)$.

Lat. 53° 01′ N. PETROPAVLOVSK, SIBERIA. Long. 158° 43′ E.

Year.	Magnetic declination.	Authority. Observer.	Where recorded.
	°		
1779.5	—6.30	Capt. J. King	A Voyage to the Pacific Ocean, London, 1784.
1792	—6.00	G. Sarycheff	F. P. Lütke's Voyage Around the World, St. Petersburg, 1835.
1804.7	—5.49	A. J. von Krusenstern	Voyage Around the World, London, 1813.
1827.6	—4.07	Capt. F. W. Beechey, 4.22	Narrative of a Voyage to the Pacific, 1825–'28, London, 1831.
		Capt. F. P. Lütke, 3.72	Lenz in Mem. St. Peters. Acad. Sc., vol. 1, 1838.
		A. G. Erman, 4.10	Reise um die Erde, Berlin, 1835.
1837.7	—3.45	Du Petit Thouars	Voyage autour dü Monde, Paris, 1843.
1849.5	—2.61	Capt. H. Kellett	Gen. Sir Edw. Sabine in Phil. Trans. Roy. Soc., vol. 162, London, 1872.
1854.6	—2.59	Frigate Aurora	Compt-rendu annuel de l'Observatoire Phys. Cent. de Russia, année, 1854.
1866	—1.41	K. S. Staritzky	Onazevich's collection of observations made during hydrographic explorations in the Pacific, 1874–'77.
1876	—1.15	M. S. Onazevich	Reference as above for 1866.
1891	+0.83	Prof. Stellingman, 1890, +.52; Lieut. Lachton, Rus. N., 1892, +1.16.	Hydrographic Office archives document.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1779.5	—6.30	—5.97	—0.33	0.1089	
1792	—6.00	—6.00	0.00	0.0000	
1804.7	—5.49	—5.70	+0.21	0.0441	
1827.6	—4.07	—4.44	+0.37	0.1369	
1837.7	—3.45	—3.68	+0.23	0.0529	Probable error of a single observation = ± 21.3′.
1849.5	—2.61	—2.70	+0.09	0.0081	Period = 252 years.
1854.6	—2.59	—1.63	—0.96	0.9216	
1866	—1.41	—1.37	—0.04	0.0016	
1876	—1.15	—0.65	—0.50	0.2500	
1891	+0.83	+0.18	+0.65	0.4225	
				1.9466	

Empirical equation for determining the declination for any year: $v = -2^\circ.682 + 3.349 \sin \frac{10}{7}(t - 1850) + 0.0156 \cos \frac{10}{7}(t - 1850)$.

Lat. 53° 10′ S. PUNTA ARENAS. Long. 70° 54′ W.

Year.	Magnetic declination.	Authority. Observer.	Authority. Where recorded.
	°		
1766*......	—22.43	22.50, Wallis, 1766...............; 22.36, Carteret, 1766...........	Voyage of the Adventure and Beagle, 1826–'36, London, 1839.
1828*......	—23.33	King	Becquerel's Traité du Magnetisme.
1831*......	—22.83	Fitz Roy.............................	Voyage of Adventure and Beagle, London, 1839.
1866........	—21.87	Harkness	Smithsonian Contributions to Knowledge, No. 239, 1873.
1872*......	—21.83	....	British Admiralty Chart, No. 547.
1883........	—20.97	20.75	British Admiralty Chart, No. 545.
		21.18, Brazilian Transit of Venus Commission.	Ann. de l'Obso. Imp. de Rio de Janeiro.
1893.3	—20.17	Lieut. L. Mottez, Fr. N......	Annales Hydrographiques, 2d vol., 1893.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1766........	—22.43	—21.82	—0.61	0.3721	Probable error of a single observation = ± 19.3′. Period = 360 years.
1828........	—23.33	—23.73	+0.40	0.1600	
1831........	—22.83	—23.67	—0.84	0.7056	
1866........	—21.87	—22.12	+0.25	0.0625	
1872........	—21.83	—21.69	—0.14	0.0196	
1883........	—20.97	—20.85	—0.12	0.0144	
1893.3	—20.17	—19.99	—0.18	0.0324	
				1.3666	

*Taken at Port Famine.

Empirical equation for determining the declination for any year: $v = -18°.68 + 2.71 \sin (t - 1850) - 4.35 \cos (t - 1850)$.

Lat. 22° 54′ S. RIO DE JANEIRO. Long. 43° 10′ W.

Year.	Magnetic declination.	Authority.	
		Observer.	Where recorded.
	°		
1768........	—7.57	Cook	Voyage of the Adventure and Beagle, London, 1839.
1783.5	—6.60	....	Anuario Hidrografico de Chile, Año XII.
1787........	—6.20	Hunter	Voyage of the Adventure and Beagle, London, 1839.
1820.5 ..	—3.66	—3.57, Freycinct, 1820........ —3.70, Rumkert and Bellinghausen, 1821............	Becquerel's Traité du Magnetisme.
1824.5	2.93	—3.00, Owen, 1822............... —3.12, Beechey, 1825......... —2.62, King, 1826................	Do.
1833........	—2.04	—2.13, Ermann, 1830........... —2.00, Fitz Roy, 1836.........	Reise um die Erde, etc., Berlin, 1835. Voyage of the Adventure and Beagle, London, 1839.
1851.9	—1.25	....	Annalen der Hydrographie, 1877.
1857........	+1.33	Stormley and Richards......	British Admiralty Chart, No. 541.
1866........	+2.70	Harkness...........................	Smithsonian Contributions to Knowledge, No. 239, 1873.
1876.5	+4.43	Lieut. S. W. Very, U. S. N..	Appendix No. 7 to Coast and Geodetic Survey Report for 1888.
1882.6	+4.65	Lieuts. Barnardières and Barnaud, Fr. N............	French Magnetic Survey. Annales Hydrographiques, 1884.
1885........	+5.33	Cruls	Anuario Hidrografico de Chile, Año XII.
1887.7	+5.95	Lieut. de Roujon, Fr. N.....	Annales de Hydrographiques, 1888.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.
	°	°		
1768........	—7.57	—7.01	—0.56	0.3136
1783.5	—6.60	—6.85	+0.25	0.0625
1787........	—6.20	—6.73	+0.53	0.2809
1820.5	—3.66	—4.03	+0.37	0.1369
1824.5	—2.93	—3.56	+0.63	0.3969
1833........	—2.04	—2.46	+0.42	0.1764
1851.9	—1.25	+0.28	—1.53	2.3409
1857........	+1.33	+1.06	+0.27	0.0729
1866........	+2.70	+2.45	+0.25	0.0625
1876.5	+4.43	+4.04	+0.39	0.1521
1882.6	+4.65	+4.94	—0.29	0.0481
1885........	+5.33	+5.29	+0.04	0.0016
1887.7	+5.95	+5.67	+0.28	0.0784
				4.1597

Probable error of a single observation = ± 26′.
Period = 360 years.

Empirical equation for determining the declination for any year: $v = 1°.814 + 8.655 \sin (t - 1850) - 1.825 \cos (t - 1850)$.

Lat. 31° 15′ N. SHANGHAI. Long. 121° 29′ E.

Year.	Magnetic declination.	Authority. Observer.	Authority. Where recorded.
	°		
1858	+1.83	Novara Expedition	Phil. Trans. Royal Society, 1875.
1875	+1.98	Jesuit missionaries	The Meteorological Elements of the Climate of Shanghai, Zi-Ka-Wei Observatory.
1876	+2.02		
1877	+2.02		
1878	+2.00		
1879	+2.02		
1880	+2.03		
1881	+2.05		
1882	+2.09		
1883	+2.08		
1884	+2.13		

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1858	1.83	1.92	−0.09	0.0081	Probable error of a single observation = ± 1.62′.
1875	1.98	2.00	−0.02	0.0004	
1876	2.02	2.01	+0.01	0.0001	
1877	2.02	2.02	0.00	0.0000	
1878	2.00	2.02	−0.02	0.0004	
1879	2.02	2.03	−0.01	0.0001	
1880	2.03	2.04	−0.01	0.0001	
1881	2.05	2.05	0.00	0.0000	
1882	2.09	2.06	+0.03	0.0009	
1883	2.08	2.07	+0.01	0.0001	
1884	2.13	2.08	+0.05	0.0025	
				0.0127	

Empirical equation for determining the declination for any year: $v = 1^\circ.9084 - 0.000012\,(t - 1850) + 0.000149\,(t - 1850)^2$.

Lat. 1° 18′ N. SINGAPORE. Long. 103° 51′ E.

Year.	Magnetic declination.	Authority.	
		Observer.	Where recorded.
	°		
1824........	—1.83	Bougainville	Becquerel's Traité du Magnetisme.
1830........	—2.00	La Place..............................	Do.
1843........	—1.72	Beecher........................	Phil. Trans. Royal Society, Part I, 1875.
1846........	—1.60	Elliott	Do.
1876.5	—2.53	Dr. van Rijckevorsel	Trans. Royal Academy of Sciences, Amsterdam, 1880.
1890.5	—2.57	Lieut. Courmes, Fr. N.........	U. S. Hydrographic Office, Notice to Mariners, No. 38, 1890.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1824........	—1.83	—1.52	—0.31	0.0961	Probable error of a single observation = ± 17′.
1830........	—2.00	—1.78	—0.22	0.0484	Period = 400 years.
1843........	—1.72	—2.03	+0.31	0.0961	
1846........	—1.60	—2.10	+0.50	0.2500	
1876.5	—2.53	—2.47	—0.06	0.0036	
1890.5	—2.57	—2.42	—0.15	0.0225	
				0.5167	

Empirical equation for determining the declination for any year: $v = 0^\circ.24 - 1.18 \sin \frac{9}{10} (t - 1850) - 2.4307 \cos \frac{9}{10} (t - 1850)$.

Lat. 15° 55′ S. ST. HELENA. Long. 5° 44′ W.

Year.	Magnetic declination.	Authority. Observer.	Authority. Where recorded.
	°		
1610.5	— 7.22	Davis	Hansteen's Magnetismus der Erde, Christiania, 1819.
1677.5	— 0.67	Halley	
1691.5	+ 1.00	do	
1724.5	+ 7.50	Mathews	
1775.5	+12.30	Cook	
1789.5	+15.50	Hunter	
1796.5	+15.80	Macdonald	
1806.5	+17.30	Krusenstern	
1839.5	+22.28	Du Petit Thouars	Magnetic and Meteorological Observations by Maj. Gen. Edw. Sabine.
1840.5	+22.88	Ross	Phil. Trans. Royal Society, Part II, 1877.
1845.5	+23.25		Do.
1846.5	+23.19	Bérard	Magnetic and Meteorological Observations by Maj. Gen. Edw. Sabine.
1890.1	+23.95	E. D. Preston, assistant, United States Coast and Geodetic Survey.	Bulletin No. 23, United States Coast and Geodetic Survey, May, 1891.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1610.5	— 7.22	—7.51	+0.29	0.0841	Probable error of a single observation = ± 41.8′. Period = 600 years.
1677.5	— 0.67	—1.29	+0.62	0.3844	
1691.5	+ 1.00	0.61	+0.39	0.1521	
1724.5	+ 7.50	5.93	+1.57	2.4649	
1775.5	+12.30	14.25	—1.95	3.8025	
1789.5	+15.50	16.31	—0.81	0.6561	
1796.5	+15.80	17.28	—1.48	2.1904	
1806.5	+17.30	17.57	—0.27	0.0729	
1839.5	+22.28	21.94	+0.34	0.1156	
1840.5	+22.88	22.55	+0.33	0.1089	
1845.5	+23.25	22.64	+0.61	0.3721	
1846.5	+23.19	22.66	+0.53	0.2809	
1890.1	+23.95	23.80	+0.15	0.0225	
				10.7074	

Empirical equation for determining the declination for any year: $v = 7°.90 + 5.92 \sin 0.6\,(t - 1850) + 14.78 \cos 0.6\,(t - 1850)$.

Lat. 33° 52′ S. SYDNEY. Long. 151° 12′ E.

Year.	Magnetic declination.	Authority. Observer.	Where recorded.
	°		
1770	— 8.00	Cook	Voyage of the Adventure and Beagle, 1826–'36, London, 1839.
1787	— 8.50	Hunter	Do.
1793.2	— 8.77		Brewster's Treatise on Magnetism, Edinburgh, 1834.
1803	— 8.85	Flinders	Voyage of the Adventure and Beagle, 1826–'36, London, 1839.
1813	— 8.87	Brewster	Hydrographic Office archives document.
1818.5	— 8.78	—8.70, Capt. King, 1817.7	Do.
		—8.93, Freycinet, 1819	Voyage of the Adventure and Beagle, 1826–'36, London, 1839.
1823	— 8.83	—8.81, Brewster, 1822	Hydrographic Office archives document.
		—8.80, Rumker and Sir T. Brisbane, 1823.	Do.
		—8.93, Brewster, 1824	Do.
1841	— 9.90	—9.85, Erebus, 1841	Phil. Trans. Royal Society, Part II, 1877.
		—9.95, Sir J. C. Ross, 1841	Hydrographic Office archives document.
1844	— 9.42	H. M S. Fly	Phil. Trans. Royal Society, Part II, 1877.
1848.5	—10.12	—10.08, Rattlesnake, 1848; —10.15, Rattlesnake, 1849	Do.
1851.5	— 9.76	—9.72, Admiral King, 1851	A letter from director of Government observatory at Sydney, dated 1890.
		—9.80, Admiral King, 1852	Do.
1858	—10.00	Capt. Denham	Do.
1864	— 9.82	Smalley	Do.
1866.5	— 9.72		
1872	— 9.57	—9.62, Russell, 1870; —9.58, Russell, 1871; —9.57, Russell, 1872; —9.53, Russell, 1873; —9.55, Russell, 1874	Do.
1875	— 9.52	—9.47, H. M. S. Challenger, May, 1874; —9.55, Russell, June, 1875	Do.
1880	— 9.58	—9.53, Russell, 1878; —9.58, Russell, 1879; —9.60, Russell, 1880; —9.60, Russell, 1881; —9.60, Russell, 1882	Do.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1770	— 8.00	—7.82	—0.18	0.0324	Probable error of a single observation = ± 10.44′. Period = 324 years.
1787	— 8.50	—8.35	—0.15	0.0225	
1793.2	— 8.77	—8.53	—0.24	0.0576	
1803	— 8.85	—8.82	—0.03	0.0009	
1813	— 8.87	—9.08	+0.21	0.0441	
1818.5	— 8.78	—9.22	+0.44	0.1936	
1823	— 8.83	—9.32	+0.49	0.2401	
1841	— 9.90	—9.62	—0.28	0.0784	
1844	— 9.42	—9.63	+0.21	0.0441	
1848.5	—10.12	—9.68	—0.44	0.1936	
1851.5	— 9.76	—9.70	—0.06	0.0036	
1858	—10.00	—9.73	— 0.27	0.0729	
1864	— 9.82	—9.72	—0.10	0.0100	
1866.5	— 9.72	—9.72	0.00	0.0000	
1872	— 9.57	—9.70	+0.13	0.0169	
1875	— 9.52	—9.67	+0.15	0.0225	
1880	— 9.58	—9.60	+0.02	0.0004	
				0.8556	

Empirical equation for determining the declination for any year: $v = -8^\circ.119 - 0.3239 \sin 1.112\,(t - 1850) - 1.5765 \cos 1.112\,(t - 1850)$.

Lat. 17° 31′ S. TAHITI, SOCIETY ISLANDS. Long. 149° 34′ W.

Year.	Magnetic declination.	Authority.	
		Observer.	Where recorded.
	°		
1768	—5.25	—5.75, Wallis, 1767	Hansteen's Magnetismus der Erde, Christiania, 1819.
		—4.75, Cook, 1769	Voyage of the Adventure and Beagle, London, 1839.
1774.6	—5.68	—5.67, Wales, 1773 —5.82, Bayley, 1774 —5.57, Cook, 1777	Do.
1794	—6.20	Vancouver	Do.
1824.3	—7.02	—6.67, Duperrey, 1823	Voyage autour du Monde, Paris, 1829.
		—6.83, Kotzebue, 1824	Phil. Trans. Royal Society, 1877.
		—7.55, Beechey, 1826	Do.
1833	—7.53	—7.50, Irland, 1831 —7.57, Fitz Roy, 1835	Do.
1838.5	—6.80	—7.17, Bruce, 1837 —6.50, Belcher, 1840	Do.
1859	—7.18	—6.90, Friesach, 1859 —7.45, Novara Ex., 1859	Do.
1871	—7.77		Hydrographic Office archives document.
1875	—7.78	—8.04, Nares & Thomson, R. N., 1875. —7.58, Nares & Thomson, R. N., 1875. —7.85, Nares & Thomson, R. N., 1875.	Report of Challenger Expedition.
1878	—7.55		Letter from French Government hydrographer.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1768	—5.25	—5.07	—0.18	0.0324	Probable error of a single observation = ± 14′. Period = 360 years.
1774.6	—5.68	—5.28	—0.40	0.1600	
1794	—6.20	—5.93	—0.27	0.0729	
1824.3	—7.02	—6.87	—0.15	0.0225	
1833	—7.53	—7.08	—0.45	0.2025	
1838.5	—6.80	—7.22	+0.42	0.1764	
1859	—7.18	—7.52	+0.34	0.1156	
1871	—7.77	—7.58	—0.19	0.0361	
1875	—7.78	—7.58	—0.20	0.0400	
1878	—7.55	—7.58	+0.03	0.0009	
				0.8593	

Empirical equation for determining the declination for any year: $v = -5°.64 - 0.8288 \sin (t - 1850) - 1.7697 \cos (t - 1850)$.

Lat. 33° 02′ S. VALPARAISO. Long. 71° 39′ W.

Year.	Magnetic declination.	Authority.	
		Observer.	Where recorded.
	°		
1709	—9.50	Feuillée	Phil. Trans. Royal Society, 1877.
1744	—12.50		Voyage of the Adventure and Beagle, London, 1839.
1793	—14.82		Do.
1802	—14.92		Becquerel's Traité du Magnetisme.
1821	—14.72	B. Hall	Do.
1823	—15.68	Morrell	Phil. Trans. Royal Society, 1877.
1825	—15.87	Beechey	Do.
1831	—15.00	King	Do.
1835	—15.30	Laplace	Do.
1837	—15.58	Beechey	Do.
1838	—15.60	La Venus	Do.
1859	—15.67	Novara Expedition	Do.
1866	—15.85	Harkness	Smithsonian Contributions to Knowledge, No. 239, 1873.
1882.6	—15.43	Lieuts. Barnardières and Barnaud, Fr. N.	French Magnetic Survey.
1883.2	—15.25	do	Annales Hydrographiques, 1884.
1884	—15.68	Lieut. J. W. Carlin, U. S. N.	Hydrographic Office Publication, No. 109.

Year.	Observed.	Computed.	O-C.	$\overline{O-C}^2$.	
	°	°			
1709	— 9.50	—10.24	+0.74	0.5476	
1744	—12.50	—11.98	—0.52	0.2704	
1793	—14.82	—14.38	—0.44	0.1936	
1802	—14.92	—14.76	—0.16	0.0256	
1821	—14.72	—15.39	+0.67	0.4489	
1823	—15.68	—15.44	—0.24	0.0576	
1825	—15.87	—15.49	—0.38	0.1444	
1831	—15.00	—15.61	+0.61	0.3721	Probable error of a single observation = ± 18 .
1835	—15.30	—15.67	+0.37	0.1369	Period = 360 years.
1837	—15.58	—15.69	+0.11	0.0121	
1838	—15.60	—15.69	+0.09	0.0081	
1859	—15.67	—15.72	+0.05	0.0025	
1866	—15.85	—15.68	—0.22	0.0484	
1882.6	—15.43	—15.24	—0.19	0.0361	
1883.2	—15.25	—15.23	—0.02	0.0004	
1884	—15.68	—15.21	—0.47	0.2209	
				2.5256	

Empirical equation for determining the declination for any year: $v = -12°.639 + 0.047 \sin (t - 1850) - 3.124 \cos (t - 1850)$.

INCLINATION.

Lat. 18° 28′ S. ARICA, PERU. Long. 70° 20.5′ W.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1768........	—28.00	....	Wilcke's Inclination Chart.
1858........	—13.67	Friesach..............................	Phil. Trans. Royal Society, 1877.
1883........	—12.76	Ensign Favereau, Fr. N......	Annales Hydrographiques, 2d series, 1884.
1893.2	—11.77	Lieutenant Mottez, Fr. N...	Annales Hydrographiques, 2d vol., 1893.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1768........	—28.00	—27.99	—0.01	0.0001	Probable error of a single observation = ± 12′.
1858........	—13.67	—13.85	+0.18	0.0324	Period = 350 years.
1883........	—12.76	—12.54	—0.22	0.0484	
1893.2	—11.77	—11.84	+0.07	0.0049	
				0.0858	

Empirical equation for determining the inclination for any year: $I = -21^\circ.67 + 7.02 \sin 1.06 (t - 1850) + 6.89 \cos 1.06 (t - 1850)$.

Lat. 7° 55.5′ S. ASCENSION ISLAND. Long. 14° 24′ W.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1754........	+11.16	De la Caille....................	Hansteen's Magnetismus der Erde, Christiania, 1819.
1775........	+ 8.95	J. Cook..........................	Do.
1822........	+ 5.16	Sabine...........................	Becquerel's Traité du Magnetisme, 1846.
1834........	+ 1.95	Allen	Phil. Trans. Royal Society, Part II, 1877.
1836........	+ 1.65	Fitz Roy................	Do.
1839........	+ 0.10	Du Petit Thouars	Do.
1842........	— 0.13	Allen.................	Do.
1852.9	— 4.12	"L'Eugenie"...............	Annalen der Hydrographie, 1877.
1863.5	1863 — 4.78	H. M. S. Hecate	Phil. Trans. Royal Society, Part II, 1877.
	1864 — 5.95	Rokeby	Do.
1876.2	— 7.75	H. M. S. Challenger......	Voyage of H. M. S. Challenger.
1890.2	—11.63	E. D. Preston, assistant, Coast and Geodetic Survey.	Coast and Geodetic Survey Report, 1891.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1754........	+11.16	+11.10	+0.06	0.0036	Probable error of a single observation = ± 44′. Period = 600 years.
1775........	+ 8.95	+10.94	—1.99	3.9601	
1822........	+ 5.16	+ 3.62	+1.54	2.3716	
1834........	+ 1.95	+ 1.33	+0.62	0.3844	
1836........	+ 1.65	+ 0.91	+0.74	0.5476	
1839........	+ 0.10	+ 0.29	—0.19	0.0361	
1842........	— 0.13	— 0.34	+0.21	0.0441	
1852.9	— 4.12	— 2.76	—1.36	1.8496	
1863.5	— 5.37	— 5.18	—0.19	0.0361	
1876.2	— 7.75	— 8.22	+0.47	0.2209	
1890.2	—11.63	—11.63	0.00	0.0000	
				9.4541	

Empirical equation for determining the inclination for any year: $I = -12°.32 - 21.24 \sin 0.6\,(t - 1850) + 10.24 \cos 0.6\,(t - 1850)$.

Lat. 13° 05′ N. BARBADOS (BRIDGETOWN). Long. 59° 37′ W.

Year.	Magnetic dip or inclination.	Authority. Observer.	Authority. Where recorded.
	°		
1722.7	44. 5	....	Appendix No. 1, Report of United States Coast and Geodetic Survey for 1895, p. 266.
1835.3	43.76	Home	Do.
1836	43.48	Home	Do.
1846	43.95	Schomburgk	Do.
1880	43.37	H. M. S. Challenger Magnetic Chart.	Report of Scientific Results of the Exploring Voyage of H. M. S. Challenger, 1873-1876, Physics and Chemistry, vol. II.
1890.3	43.13	E. D. Preston, assistant, United States Coast and Geodetic Survey.	Bulletin No. 23, United States Coast and Geodetic Survey, March, 1891.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1722.7	44. 5	44.49	+0.01	.0001	Probable error of a single observation = ± 8′.
1835.7	43.62	43.82	—0.20	.0400	
1846	43.95	43.70	+0.25	.0625	
1880	43.37	43.34	+0.03	.0009	
1890.5	43.13	43.23	—0.10	.0100	
				.1135	

Empirical equation for determining the inclination for any year: $I = +43^\circ.66 - 0.0108\,(t - 1850) - 0.000034\,(t - 1850)^2$.

Lat. 6° 08′ S. BATAVIA. Long. 106° 48′ E.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1768........	—40.00	....	Wilcke's Inclination Chart.
1828........	—25.93	Blosseville..................................	Phil. Trans. Royal Society, Part II, 1877.
1846........	—27.08	Elliot..	Do.
1858........	—27.58	Novara expedition..............	Do.
1876........	—27.63	Van Rijckevorsel...............	Magnetic Survey of the Eastern part of Brazil, published by the Royal Academy of Sciences, Amsterdam.
1882.7	—28.07	Observatory..........................	Magnetic and Meteorological Observations at the Batavian Observatory.
1883.5	—27.96	.... do..................................	Do.
1884.5	—28.05	.... do..................................	Do.
1885.5	—28.17	.... do..................................	Do.
1886.5	—28.24	.... do..................................	Do.
1887.5	—28.35	.... do..................................	Do.
1888.5	—28.42	.... do..................................	Do.
1889.5	—28.51	.... do..................................	Do.
1890.5	—28.72	.... do..................................	Do.
1891.5	—28.85	.... do..................................	Do.
1892.5	—28.97	.... do..................................	Do.
1893.5	—29.10	.... do..................................	Do.
1894.5	—29.23	.... do..................................	Do.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1768........	—40.00	—38.97	—1.03	1.0609	
1828........	—25.93	—28.20	+2.27	5.1529	
1846........	—27.08	—26.73	—0.35	0.1225	
1858........	—27.58	—26.48	—1.10	1.2100	
1876........	—27.63	—27.25	—0.38	0.1444	
1882.7	—28.07	—27.86	—0.21	0.0441	
1883.5	—27.96	—27.95	—0.01	0.0001	
1884.5	—28.05	—28.06	+0.01	0.0001	
1885.5	—28.17	—28.17	—0.00	0.0000	Probable error of a single observation = ± 29′.
1886.5	—28.24	—28.26	+0.02	0.0004	Period = 300 years.
1887.5	—28.35	—28.41	+0.06	0.0036	
1888.5	—28.42	—28.52	+0.10	0.0100	
1889.5	—28.51	—28.65	+0.14	0.0196	
1890.5	—28.72	—28.79	+0.07	0.0049	
1891.5	—28.85	—28.92	+0.07	0.0049	
1892.5	—28.97	—29.06	+0.09	0.0081	
1893.5	—29.10	—29.19	+0.09	0.0081	
1894.5	—29.23	—29.33	+0.10	0.0100	
				7.8046	

Empirical equation for determining the inclination for any year: $I = -36°.19 + 1.40 \sin 1.2 (t - 1850) + 9.61 \cos 1.2 (t - 1850)$.

Lat. 18° 56′ N. BOMBAY. Long. 72° 54′ E.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1845	+17.98	Orlebar	Phil. Trans. Royal Society, 1875.
1847	+18.30	Montrion	Do.
1849	+18.87	Cassini	Annales Hydrographiques, 1851.
1856	+19.10	Schlagintweit	Phil. Trans. Royal Society, 1875.
1863	+19.22		Johnson's Encyclopedia.
1867.5	+19.03	Observatory	Phil. Trans. Royal Society, 1875.
1868.5	+19.07	do	Phil. Trans. Royal Society, 1876.
1869.5	+19.10	do	Do.
1870.5	+19.13	do	Do.
1871.5	+19.15	do	Bombay Magnetic and Meteorological Observations.
1872.5	+19.23	do	Do.
1873.5	+19.25	do	Do.
1874.5	+19.25	do	Do.
1875.5	+19.22	do	Do.
1876.5	+19.20	do	Do.
1877.5	+19.33	do	Do.
1878.5	+19.33	do	Do.
1879.5	+19.37	do	Do.
1880.5	+19.37	do	Do.
1881.5	+19.53	do	Do.
1882.5	+19.72	do	Do.
1883.5	+19.72	do	Do.
1884.5	+19.75	do	Do.
1885.5	+19.77	do	Do.
1886.5	+19.77	do	Do.
1887.5	+19.77	do	Do.
1888.5	+20.18	do	Do.
1889.5	+20.27	do	Do.
1890.5	+20.33	do	Do.
1891.5	+20.42	do	Do.
1892.5	+20.50	do	Do.
1893.5	+20.58	do	Do.
1894.5	+20.68	do	Do.

BOMBAY—Continued.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1845........	+17.98	+18.39	—0.41	0.1681	
1847........	+18.30	+18.43	—0.13	0.0169	
1849........	+18.87	+18.45	+0.42	0.1764	
1856........	+19.10	+18.59	+0.51	0.2601	
1863........	+19.22	+18.81	+0.41	0.1681	
1867.5	+19.03	+18.97	+0.06	0.0036	
1868.5	+19.07	+19.02	+0.05	0.0025	
1869.5	+19.10	+19.06	+0.04	0.0016	
1870.5	+19.13	+19.11	+0.02	0.0004	
1871.5	+19.15	+19.15	+0.00	0.0000	
1872.5	+19.23	+19.20	+0.03	0.0009	
1873.5	+19.25	+19.24	+0.01	0.0001	
1874.5	+19.25	+19.29	—0.04	0.0016	
1875.5	+19.22	+19.33	—0.11	0.0121	
1876.5	+19.20	+19.39	—0.19	0.0361	
1877.5	+19.33	+19.43	—0.10	0.0100	Probable error of a single observation = ± 8′.
1878.5	+19.33	+19.48	—0.15	0.0225	Period = 600 years.
1879.5	+19.37	+19.54	—0.17	0.0289	
1880.5	+19.37	+19.61	—0.24	0.0576	
1881.5	+19.53	+19.66	—0.13	0.0169	
1882.5	+19.72	+19.73	—0.01	0.0001	
1883.5	+19.72	+19.77	—0.05	0.0025	
1884.5	+19.75	+19.84	—0.09	0.0081	
1885.5	+19.77	+19.91	—0.14	0.0196	
1886.5	+19.77	+19.96	—0.19	0.0361	
1887.5	+19.77	+20.02	—0.25	0.0625	
1888.5	+20.18	+20.09	+0.09	0.0081	
1889.5	+20.27	+20.15	+0.12	0.0144	
1890.5	+20.33	+20.23	+0.10	0.0100	
1891.5	+20.42	+20.29	+0.13	0.0169	
1892.5	+20.50	+20.35	+0.15	0.0225	
1893.5	+20.58	+20.42	+0.16	0.0256	
1894.5	+20.68	+20.50	+0.18	0.0324	
				1.2432	

Empirical equation for determining the inclination for any year: $I = 30^\circ.47 + 1.67 \sin 0.6\,(t - 1850) - 12.00 \cos 0.6\,(t - 1850)$.

Lat. 12° 04′ S. CALLAO, PERU. Long. 77° 08′ W.

Year.	Magnetic dip or inclination.	Authority. Observer.	Authority. Where recorded.
	°		
1790	—12.37	Malaspina	Bode's Astronomisches Jahrbuch, 1828.
1823	— 8.55	Duperrey	Voyages of the Adventure and Beagle, 1826–1836, London, 1839.
1835	— 7.05	Fitz Roy	Do.
1838	— 6.23	Belcher	Phil. Trans. Royal Society, Part II, 1877.
1838	— 6.82	"La Venus"	Do.
1858	— 7.17	Friesach	Do.
1866	— 6.47	Harkness	Do.
1893	— 5.25	Lieutenant Mottez, Fr. N.	Annales Hydrographiques, 2d vol., 1893.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1790	—12.37	—12.17	—0.20	0.0400	Probable error of a single observation = ± 31′.
1823	— 8.55	— 8.34	—0.21	0.0441	
1835	— 7.05	— 7.37	+0.32	0.1024	
1838	— 6.23	— 7.16	+0.93	0.8649	
1838	— 6.82	— 7.16	+0.34	0.1156	
1858	— 7.17	— 6.12	—1.05	1.1025	
1866	— 6.47	— 5.86	—0.61	0.3721	
1893	— 5.25	— 5.75	+0.50	0.2500	
				2.8916	

Empirical equation for determining the inclination for any year: $I = -6^\circ.46 + 0.0495\,(t - 1850) - 0.00076\,(t - 1850)^2$.

Lat. 33° 56′ S. CAPE OF GOOD HOPE. Long. 18° 29′ E.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1751	—43.00		On the Causes of Phenomenon of Terrestrial Magnetism, by Wilde.
1770	—44.37	C. G. Ekeberg	Hansteen's Magnetismus der Erde, Christiania, 1819.
1774	—44.48	do	Do.
1775	—45.32		On the Causes of Phenomenon of Terrestrial Magnetism, by Wilde.
1780	—46.77		Do.
1792	—47.42		Do.
1818	—50.67		Do.
1836	—52.58		Do.
1839	—53.10		Do.
1841.5	—53.15	Observatory	Phil. Trans. Royal Society, 1877.
1842.5	—53.22	do	Do.
1843.5	—53.32	do	Do.
1844.5	—53.60	do	Do.
1845.5	—53.53	do	Do.
1846.5	—53.55	do	Do.
1847.5	—53.68	do	Do.
1848.5	—53.78	do	Do.
1849.5	—53.87	do	Do.
1850.5	—53.97	do	Do.
1851.5	—54.03	do	Do.
1857.0	—54.60	Novara Expedition	Do.
1873.9	—55.93	H. M. S. Challenger	Voyage of H. M. S. Challenger.
1880	—57.00		On the Causes of Phenomenon of Terrestrial Magnetism, by Wilde.
1890.1	—57.25	E. D. Preston, assistant, United States Coast and Geodetic Survey.	Coast and Geodetic Survey Report, 1891.

CAPE OF GOOD HOPE—Continued.

Year.	Observed.	Computed.	O-C.	$\overline{O-C}^2$.	
	°	°			
1751........	—43.00	—42.93	—0.07	0.0049	
1770........	—44.37	—44.77	+0.40	0.1600	
1774........	—44.48	—45.21	+0.73	0.5329	
1775........	—45.32	—45.32	0.00	0.0000	
1780........	—46.77	—45.87	—0.90	0.8100	
1792........	—47.42	—47.28	—0.14	0.0196	
1818........	—50.67	—50.44	—0.23	0.0529	
1836........	—52.58	—52.55	—0.03	0.0009	
1839	—53.10	—52.87	—0.23	0.0529	
1841.5	—53.15	—53.16	+0.01	0.0001	
1842.5	—53.22	—53.26	+0.04	0.0016	
1843.5	—53.32	—53.37	+0.05	0.0025	Probable error of a single observation = ± 12.6′.
1844.5	—53.60	—53.47	—0.13	0.0169	Period = 450 years.
1845.5	—53.53	—53.58	+0.05	0.0025	
1846.5	—53.55	—53.69	+0.14	0.0196	
1847.5	—53.68	—53.79	+0.11	0.0121	
1848.5	—53.78	—53.89	+0.11	0.0121	
1849.5	—53.87	—53.99	+0.12	0.0144	
1850.5	—53.97	—54.09	+0.12	0.0144	
1851.5	—54.03	—54.19	+0.16	0.0256	
1857.0	—54.60	—54.73	+0.13	0.0169	
1873.9	—55.93	—56.13	+0.20	0.0400	
1880........	—57.00	—56.56	—0.44	0.1936	
1890.1	—57.25	—57.13	—0.12	0.0144	
				2.0229	

Empirical equation for determining the inclination for any year: $I = -49°.11 - 7.23 \sin 0.8 (t - 1850) - 4.93 \cos 0.8 (t - 1850)$.

Lat. 19° 26′ N. CITY OF MEXICO. Long. 90° 05′ W.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1778........	+38.00	Don Alzate	Encyclopedia Metropolitana, 1848.
1799........	+42.17	A. von Humboldt.................	Do.
1856........	+41.43	Müller and Sontag	Phil. Trans. Royal Society, 1875.
1858........	+41.44	.... do...............................	Smithsonian Contributions to Knowledge, 1860.
1879.7	+44.86	V. Reyes	Memoria sobre el Dept. Magnetico, etc., Mexico, 1880.
1884........	+45.02	M. Barcena..........................	United States Coast and Geodetic Survey Report for 1885, Appendix No. 6.
1888........	+45.05	Observatory	Mem. del Observatorio Met. Central de Mexico.
1890........	+44.05	.... do...............................	Do.
1895........	+44.37	.... do...............................	Boletín del Observatorio Astronómico Nacional de Tacubaya, Tomo 1, 1896.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1778........	+38.00	+39.40	−1.40	1.9600	
1799........	+42.17	+39.74	+2.43	5.9049	
1856........	+41.43	+42.66	−1.23	1.5129	
1858........	+41.44	+42.77	−1.33	1.7689	
1879.7	+44.86	+43.99	+0.87	0.7569	Probable error of a single observation = ± 60′. Period = 300 years.
1884........	+45.02	+44.20	+0.82	0.6724	
1888........	+45.05	+44.38	+0.67	0.4489	
1890........	+44.05	+44.46	−0.41	0.1681	
1895........	+44.37	+44.66	−0.29	0.0841	
				13.2771	

Empirical equation for determining the inclination for any year: $I = 42^\circ.32 + 2.92 \sin 1.2\,(t - 1850) - 0.04 \cos 1.2\,(t - 1850)$.

Lat. 36° 42′ S. CONCEPCION. Long. 73° 07′ W.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1710	—55.50	Feuillée	Hansteen's Magnetismus der Erde, Christiania, 1819.
1768	—55.50		Wilcke's Magnetic Chart.
1794	—52.18	Malaspina	Berliner Astronomisches Jahrbuch, 1828.
1823	—44.70	Duperrey	Phil. Trans. Royal Society, 1877.
1827	—45.55	Lütke	Do.
1829	—45.18	King	Do.
1835	—43.25	Fitz Roy	Do.
1882.7	—37.97	Lieutenants Barnaud and Barnadières, Fr. N.	Annales Hydrographiques, 1884.
1893.2	—36.67	Lieut. Mottez, Fr. N.	Annales Hydrographiques, vol. II, 1893.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1710	—55.50	—56.01	+0.51	0.2601	Probable error of a single observation = ± 38′. Period = 400 years.
1768	—55.50	—54.73	—0.77	0.5929	
1794	—52.18	—51.12	—1.06	1.1236	
1823	—44.70	—46.17	+1.47	2.1609	
1827	—45.55	—45.49	—0.06	0.0036	
1829	—45.18	—45.15	—0.03	0.0009	
1835	—43.25	—44.10	+0.85	0.7225	
1882.7	—37.97	—37.32	—0.65	0.4225	
1893.2	—36.67	—36.38	—0.29	0.0841	
				5.3711	

Empirical equation for determining the inclination for any year: $I = -46°.42 + 10.05 \sin 0.9 (t - 1850) + 4.80 \cos 0.9 (t - 1850)$.

Lat. 29° 57′ S. COQUIMBO. Long. 71° 22′ W.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1710	—47.42	Feuillée	Hansteen's Magnetismus der Erde, 1819.
1791	—40.45	Malaspina	Berliner Astronomisches Jahrbuch, 1828.
1868	—29.92	H. M. S. Nassau	Phil. Trans. Royal Society, 1877.
1883	—29.40	Ensign Favereau, Fr. N.	Annales Hydrographiques, 2d series, 1884.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1710	—47.42	—47.43	+0.01	0.0001	Probable error of a single observation = ± 3′.
1791	—40.45	—40.46	+0.01	0.0001	Period = 327 years.
1868	—29.92	—29.87	—0.05	0.0025	
1883	—29.40	—29.45	+0.05	0.0025	
				0.0052	

Empirical equation for determining the inclination for any year: $I = -38°.53 + 5.51 \sin 1.1 (t - 1850) + 7.22 \cos 1.1 (t - 1850)$.

Lat. 38° 32′ N. FAYAL, AZORES. Long. 28° 33′ W.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1767*	72.00	C. G. Ekeberg	Hansteen's Magnetismus der Erde, 1819.
1775.5	71.02	Cook	Coast and Geodetic Survey Report for 1891.
1805.5	67.20	Von Humboldt	Beiträge zur Kenntniss des Wesens der Säcular-Variation des Erdmagnetismus, von L. A. Bauer.
1831.5	68.57	Austin, Foster	Do.
1850	65.88	Rattlesnake	Do.
1873.5	64.95	H. M. S. Challenger	Do.
1880.7	63.64	Thorpe	Do.
1889.8	64.23	E. D. Preston, assistant, United States Coast and Geodetic Survey.	Coast and Geodetic Survey Report for 1891.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1767*	72.00	70.93	+1.07	1.1449	Probable error of a single observation = ± 47′. Period = 450 years.
1775.5	71.02	70.51	+0.51	0.2601	
1805.5	67.20	68.75	—1.55	2.4025	
1831.5	68.57	67.11	+1.46	2.1316	
1850	65.88	65.93	—0.05	0.0025	
1873.5	64.95	64.69	+0.26	0.0676	
1880.7	63.64	64.35	—0.71	0.5041	
1889.8	64.23	63.96	+0.27	0.0729	
				5.4413	

* Omitted.

Empirical equation for determining the inclination for any year: $I = 67°.80 - 4.87 \sin [0.75 (t - 1850) + 22.1]$.

This equation was deduced by Dr. L. A. Bauer with the above data.

Lat. 23° 09′ N. HABANA. Long. 82° 22′ W.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1801........	+53.37	A. von Humboldt................	Becquerel's Traité du Magnétisme, 1846.
1822........	+51.92	Sabine..................................	Phil. Trans. Royal Society, Part I, 1875.
1857.......	+52.00	Friesach.............................	Do.
1879........	+52.30	Lieut. Commander Ackley, U. S. N.	Report of Coast and Geodetic Survey, 1881.
1885.9	+52.33	....	Observaciones Magnéticas y Meteorológicas del Real Colegio de Belen, 1876.
1887.3	+52.17	Lieut. Aubry, Fr. N............	Annales Hydrographiques, vol. II, 1888.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1801........	+53.37	+53.36	+0.01	0.0001	Probable error of a single observation = ± 14′.
1822........	+51.92	+52.35	—0.43	0.1849	
1857........	+52.00	+51.74	+0.26	0.0676	
1879........	+52.30	+52.03	+0.27	0.0729	
1885.9	+52.33	+52.26	+0.07	0.0049	
1887.3	+52.17	+52.30	—0.13	0.0169	
				0.3473	

Empirical equation for determining the inclination for any year: $I = 51°.76 - 0.0058\ (t - 1850) + 0.00055\ (t - 1850)^2$.

Lat. 22° 16′ N. HONGKONG. Long. 114° 10′ E.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1791	+27.92	Malaspina	Bode's Astronomisches Jahrbuch, 1828.
1827	+29.95	Beechey	Phil. Trans. Royal Society, Part I, 1875.
1837	+30.53	Darandeau	Do.
1841.1	+30.05	Observatory	Observations and Researches at the Hongkong Observatory, 1885. (See Appendix A.)
1843	+30.05	Belcher	Phil. Trans. Royal Society, Part I, 1875.
1843.8	+30.83	Observatory	Observations and Researches at the Hongkong Observatory, 1885. (See Appendix A.)
1851	+29.67	Collinson	Phil. Trans. Royal Society, Part I, 1875.
1858	+31.13	Novara Expedition	Do.
1858.1	+31.10	Observatory	Observations and Researches at the Hongkong Observatory, 1885. (See Appendix A.)
1872.3	+32.30	Shadwell	Phil. Trans. Royal Society, Part I, 1877.
1873.3	+32.33	do	Do.
1874.3	+32.29	do	Do.
1875	+32.34	H. M. S. Challenger	Voyage of H. M. S. Challenger.
1875	+32.30	do	Do.
1875.7	+31.95	Fritsche	Ergänzungsheft No. 77 zu Petermann's Mittheilungen, Band XVIII, 1884–'85.
1884.5	+32.45	Observatory	Observations and Researches at the Hongkong Observatory, W. Doberck, director.
1885.5	+32.44	do	Do.
1886.5	+32.43	do	Do.
1887.5	+32.37	do	Do.
1888.5	+32.35	do	Do.
1889.5	+32.28	do	Do.
1890.2	+32.17	do	Do.
1891.3	+32.40	Lieut. De Roujon, Fr. N.	Annales Hydrographiques, 2nd series, 1st vol., 1892.
1891.8	+32.08	Observatory	Observations and Researches at the Hongkong Observatory, W. Doberck, director.
1892.5	+32.05	do	Do.
1893.5	+31.95	do	Do.
1894.5	+31.88	do	Do.

HONGKONG—Continued.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1791.......	+27.92	+26.99	+0.93	0.8649	
1827........	+29.97	+29.89	+0.08	0.0064	
1837........	+30.53	+30.18	+0.35	0.1225	
1841.1	+30.05	+30.44	—0.39	0.1521	
1843........	+30.05	+30.58	—0.53	0.2809	
1843.8	+30.83	+30.59	+0.24	0.0625	
1851........	+29.67	+30.99	—1.32	1.7689	
1858........	+31.13	+31.34	—0.21	0.0441	
1858.1	+31.10	+31.35	—0.25	0.0625	
1872.3	+32.30	+31.91	+0.39	0.1521	
1873.3	+32.33	+31.91	+0.42	0.1764	
1874.3	+32.29	+31.98	+0.31	0.0961	
1875........	+32.34	+32.00	+0.34	0.1156	Probable error of a single observation = ± 18′.
1875........	+32.30	+32.00	+0.30	0.0900	Period = 400 years.
1875.7	+31.95	+32.02	—0.07	0.0049	
1884.5	+32.45	+32.23	+0.22	0.0484	
1885.5	+32.44	+32.26	+0.18	0.0324	
1886.5	+32.43	+32.27	+0.16	0.0256	
1887.5	+32.37	+32.29	+0.08	0.0064	
1888.5	+32.35	+32.31	+0.04	0.0016	
1889.5	+32.28	+32.32	—0.04	0.0016	
1890.2	+32.17	+32.34	—0.17	0.0289	
1891.3	+32.40	+32.35	+0.05	0.0025	
1891.8	+32.08	+32.35	—0.27	0.0729	
1892.5	+32.05	+32.36	—0.31	0.0961	
1893.5	+31.95	+32.37	—0.42	0.1764	
1894.5	+31.88	+32.38	—0.50	0.2500	
				4.7427	

Empirical equation for determining the inclination for any year: $I = 27°.82 + 3.38 \sin 0.9\,(t - 1850) + 3.12 \cos 0.9\,(t - 1850)$.

Lat. 21° 18′ N. HONOLULU. Long. 157° 52′ W.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1830	41.70	Douglas	Phil. Trans. Royal Society, Part I, 1875.
1836	42.10	"Bonite"	Do.
1837	41.60	Beechey	Do.
1838	41.30	Belcher	Do.
1852.5	41.18	Swedish Magnetic Survey	Annalen der Hydrographie, 1877.
1875.5	39.78	H. M. S. Challenger	Voyage of H. M. S. Challenger.
1890.6	40.53	Lieutenant Courmes, Fr. N.	Annales Hydrographiques, 2d vol., 1892.
1892.5	40.70	E. D. Preston, assistant, United States Coast and Geodetic Survey.	Report of United States Coast and Geodetic Survey, Part II, 1893.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1830	+41.70	+42.10	—0.40	0.1600	Probable error of a single observation = ± 17′.
1836	+42.10	+41.65	+0.45	0.2025	
1837	+41.60	+41.59	+0.01	0.0001	
1838	+41.30	+41.51	—0.21	0.0441	
1852.5	+41.18	+40.74	+0.44	0.1936	
1875.5	+39.78	+40.28	—0.50	0.2500	
1890.6	+40.53	+40.50	+0.03	0.0009	
1892.5	+40.70	+40.55	+0.15	0.0225	
				0.8737	

Empirical equation for determining the inclination for any year: $I = 40^\circ.31 - 0.0093\,(t - 1870) + 0.00089\,(t - 1870)^2$.

Lat. 24° 38′ N. MAGDALENA BAY. Long. 112° 07′ W.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1837........	+50.72	Du Petit Thouars................	Phil. Trans. Royal Society, 1875.
1866.5	+48.53	Harkness	Smithsonian Contributions to Knowledge, No. 239, 1873.
1873.2	+48.15	W. Eimbeck, assistant, Coast and Geodetic Survey.	Coast and Geodetic Survey Report for 1881.
1881.2	+48.32	Lieut. Commander H. E. Nichols, U. S. N.	Do.
1895.2	+48.52	Lieut. F. M. Bostwick, U. S. N.	Hydrographic Office archives document.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1837........	+50.72	+50.71	+0.01	0.0001	Probable error of a single observation = ± 5′.
1866.5	+48.53	+48.46	+0.07	0.0049	
1873.2	+48.15	+48.28	−0.13	0.0169	
1881.2	+48.32	+48.23	+0.09	0.0081	
1895.2	+48.52	+48.54	−0.02	0.0004	
				0.0304	

Empirical equation for determining the inclination for any year: $I = 48°.26 - 0.0135\ (t - 1875) + 0.00135\ (t - 1875)^2$.

Lat. 14° 36′ N. MANILA. Long. 120° 58′ E.

Year.	Magnetic dip or inclination.	Authority. Observer.	Where recorded.
	°		
1766	+11.68	Le Gentil	Hansteen's Magnetismus der Erde, Christiania, 1819.
1786	+11.08	"Boussole"	Do.
1792.6	+10.67	Malaspina	Berliner Astronomisches Jahrbuch, 1828.
1829	+16.27	Lütke	Phil. Trans. Royal Society, 1875.
1836	+16.50	"Bonite"	Do.
1840	+16.45		El Magnetismo Terrestre en Filipinas, 1893.
1844	+16.43	Belcher	Phil. Trans. Royal Society, 1875.
1853	+15.58	"L'Eugene"	Annalen der Hydrographie, 1877.
1874	+17.98	H. M. S. Challenger	Voyage of H. M. S. Challenger.
1887.5	+17.47	Observatory	El Magnetismo Terrestre en Filipinas, 1893.
1889.5	+17.38	do	Do.
1890.5	+17.37	do	Do.
1891.5	+17.27	do	Do.
1891.9	+17.23	H. M. S. Penguin	Phil. Trans. Royal Society, 1896, A.
1892.5	+17.18	Observatory	El Magnetismo Terrestre en Filipinas, 1893.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1766	+11.68	+10.19	+1.49	2.2201	
1786	+11.08	+11.83	—0.75	0.5625	
1792.6	+10.67	+12.40	—1.73	2.9929	
1829	+16.27	+15.35	+0.92	0.8464	
1836	+16.50	+15.82	+0.68	0.4624	
1840	+16.45	+16.06	+0.39	0.1521	
1844	+16.43	+16.29	+0.14	0.0196	
1853	+15.58	+16.75	—1.17	1.3689	Probable error of a single observation = ± 35′. Period = 360 years.
1874	+17.98	+17.37	+0.61	0.3721	
1887.5	+17.47	+17.42	+0.05	0.0025	
1889.5	+17.38	+17.40	—0.02	0.0004	
1890.5	+17.37	+17.39	—0.02	0.0004	
1891.5	+17.27	+17.39	—0.12	0.0144	
1891.9	+17.23	+17.38	—0.15	0.0225	
1892.5	+17.18	+17.37	—0.19	0.0361	
				9.0733	

Empirical equation for determining the inclination for any year: $I = 12°.49 + 2.74 \sin (t - 1850) + 4.11 \cos (t - 1850)$.

Lat. 34° 54′ S. MONTEVIDEO. Long. 56° 12′ W.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1790........	—42.22	Malaspina	Berliner Astronomisches Jahrbuch, 1828.
1827........	—36.47	King	Phil. Trans. Royal Society, Part II, 1877.
1833........	—34.85	Fitz Roy............................	Do.
1836........	—34.83	" Bonite "	Do.
1838........	—34.05	Sulivan	Do.
1852........	—32.12	Macrae	Do.
1866........	—31.10	Harkness	Do.
1867........	—31.03	H. M. S. Nassau..................	Do.
1876.2	—29.81	H. M. S. Challenger.....	Voyage of H. M. S. Challenger.
1882.7	—29.33	Lieutenants Barnaud and Barnardières, Fr. N.	Annales Hydrographiques, 1884.
1893.4	—28.13	Lieutenant Mottez, Fr. N....	Annales Hydrographiques, vol. II, 1893.
1895.9	—28.30	Lieutenant Schwerer, Fr.N.	Annales Hydrographiques, 1896.

Year.	Observed.	Computed.	O-C.	$\overline{O-C}^2$.	
	°	°			
1790........	—42.22	—42.22	+0.00	0.0000	
1827........	—36.47	—35.94	—0.53	0.2809	
1833........	—34.85	—35.06	+0.21	0.0441	
1836........	—34.83	—34.64	—0.19	0.0361	
1838........	—34.05	—34.36	+0.31	0.0961	
1852........	—32.12	—32.53	+0.41	0.1681	
1866........	—31.10	—30.92	—0.18	0.0324	Probable error of a single observation = ± 12′.
1867........	—31.03	—30.82	—0.21	0.0441	
1876.2	—29.81	—29.88	+0.07	0.0049	
1882.7	—29.33	—29.27	—0.06	0.0036	
1893.4	—28.13	—28.38	+0.25	0.0625	
1895.9	—28.30	—28.14	—0.16	0.0256	
				0.7984	

Empirical equation for determining the inclination for any year: $I = -32°.78 + 0.125\,(t - 1850) - 0.00054\,(t - 1850)^2$.

Lat. 5° 05′ S. PAITA, PERU. Long. 81° 05.5′ W.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1823	+4.02	4.11, Duperrey	Becquerel's Traité du Magnetisme, 1846.
		3.93, Duperrey	Phil. Trans. Royal Society, 1877.
1832	+4.67	Boussingault	Do.
1836	+4.42	"La Bonite"	Do.
1838	+4.53	"La Venus"	Do.
1866	+4.97	Harkness	Do.
1893.9	+6.07	Lieutenant Mottez, Fr. N.	Annales Hydrographiques, vol. 1, 1893.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1823	+4.02	+4.22	−0.20	0.0400	Probable error of a single observation = ± 14′.
1832	+4.67	+4.38	+0.29	0.0841	
1836	+4.42	+4.45	−0.03	0.0009	
1838	+4.53	+4.50	+0.03	0.0009	
1866	+4.97	+5.14	−0.17	0.0289	
1893.9	+6.07	+5.99	+0.08	0.0064	
				0.1612	

Empirical equation for determining the inclination for any year: $I = 4°.75 + 0.0231\,(t - 1850) + 0.000119\,(t - 1850)^2$.

Lat. 8° 57′ N. PANAMA. Long. 79° 32′ W.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1790........	+29.48	Malaspina	Bode's Astronomisches Jahrbuch, 1828.
1837........	+31.87	E. Belcher	Phil. Trans. Royal Society, 1843.
1849........	+32.00	Emory	Phil. Trans. Royal Society, Part I, 1875.
1858........	+32.50	R. W. Haig	Phil. Trans. Royal Society, 1864.
1866........	+31.93	Harkness............................	Smithsonian Contributions to Knowledge, No. 239, 1873.
1891.4	+31.32	Lieutenant Courmes, Fr. N..	Annales Hydrographiques, 1892.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1790........	+29.48	+29.43	+0.05	0.0025	Probable error of a single observation = ± 6′.
1837........	+31.87	+31.90	—0.03	0.0009	
1849........	+32.00	+32.08	—0.08	0.0064	
1858........	+32.50	+32.11	+0.22	0.0484	
1866........	+31.93	+32.04	—0.11	0.0121	
1891.4	+31.32	+31.34	—0.02	0.0004	
				0.0707	

Empirical equation for determining the inclination for any year: $I = 32°.09 + 0.0071\ (t - 1850) - 0.00061\ (t - 1850)^2$.

Lat. 8° 03′ S. PERNAMBUCO. Long. 34° 52′ W.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1768	+10.00		Wilcke's Inclination Chart.
1836	+13.22	Fitz Roy	Phil. Trans. Royal Society, Part II, 1877.
1839	+13.15	Sulivan	Do.
1865	+12.13	Harkness	Do.
1881.5	+ 8.95	Van Rijckevorsel	Magnetic Survey of Eastern part of Brazil, published by Royal Academy of Sciences, Amsterdam, 1890.
1896	+ 8.00		Annales Hydrographiques, 1896.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1768	+10.00	+ 9.66	+0.34	0.1156	Probable error of a single observation = ± 25′. Period = 360 years.
1836	+13.22	+13.37	−0.15	0.0225	
1839	+13.15	+13.26	−0.11	0.0121	
1865	+12.13	+11.49	+0.64	0.4096	
1881.5	+ 8.95	+ 9.66	−0.71	0.5041	
1896	+ 8.00	+ 7.76	+0.24	0.0576	
				1.1215	

Empirical equation for determining the inclination for any year: $I = 5°.27 - 3.70 \sin (t - 1850) + 7.42 \cos (t - 1850)$.

Lat. 53° 01′ N. PETROPAVLOVSK. Long. 158° 43′ E.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1779.7	+63.08	J. King..............................	Voyage to the Pacific, 1784.
1804.7	+63.53	A. J. von Krusenstern........	Coast and Geodetic Survey Report for 1885, Appendix No. 6.
1827.6	+64.03	F. W. Beechey	Voyage to the Pacific, 1825–28, London, 1831.
1827.8	+64.12	F. P. Lütke.........................	Mémoires, St. Petersburg Acad., 1838.
1829.8	+63.82	Ad. Erman..........................	Reise um die Erde, Berlin, 1835.
1837.7	+64.08	Du Petit Thouars	Voyage autour du Monde, Paris, 1843.
1854.6	+64.78	....	Frigate Aurora.
1876.5	+64.23	M. L. Onazevich..................	Magnetic Observations obtained in 1890 in the East Siberian Sea provinces by E. Schtelling.
1890........	+64.48	E. Schtelling	Do.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1779.7	+63.08	+63.17	—0.09	0.0081	Probable error of a single observation = ± 10′. Period = 360 years.
1804.7	+63.53	+63.59	—0.06	0.0036	
1827.6	+64.03	+63.97	+0.06	0.0036	
1827.8	+64.12	+63.98	+0.14	0.0196	
1829.8	+63.82	+64.00	—0.18	0.0324	
1837.7	+64.08	+64.12	—0.04	0.0016	
1854.6	+64.78	+64.33	+0.45	0.2025	
1876.5	+64.23	+64.49	—0.26	0.0676	
1890.0	+64.48	+64.53	—0.05	0.0025	
				0.3415	

Empirical equation for determining the inclination for any year: $I = 63°.54 + 0.66 \sin (t - 1850) + 0.74 \cos (t - 1850)$.

Lat. 53° 10′ S. PUNTA ARENAS. Long. 70° 54′ W.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1760........	*—65.00	Cook....................................	Hansteen's Magnetismus der Erde, 1819.
1769........	*—68.85	......do..................................	Do.
1852........	—57.42	"L'Eugenie"	Annalen der Hydrographie, 1877.
1866........	—54.95	Harkness	Smithsonian Contributions to Knowledge, 1873.
1876........	—53.06	H. M. S. Challenger............	Voyage of H. M. S. Challenger.
1883........	—52.77	Brazilian Transit of Venus Commission.	Ann. de l'Obs. Imp. de Rio de Janeiro.
1893.3	—51.33	Lieutenant Mottez, Fr. N....	Annales Hydrographiques, 2d vol., 1893.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1760........	—65.00	—66.87	+1.87	3.4969	Probable error of a single observation = ± 59′. Period = 400 years.
1769........	—68.85	—66.77	—2.08	4.3264	
1852........	—57.42	—57.56	+0.14	0.0196	
1866........	—54.95	—55.22	+0.27	0.0729	
1876........	—53.06	—53.58	+0.52	0.2704	
1883........	—52.77	—52.47	—0.30	0.0900	
1893.3	—51.33	—50.91	—0.42	0.1764	
				8.4526	

* Observed at Good Success Bay, Tierra del Fuego.

Empirical equation for determining the inclination for any year: $I = -56°.23 + 10.51 \sin 0.9 (t - 1850) - 1.66 \cos 0.9 (t - 1850)$.

Lat. 22° 54′ S. RIO DE JANEIRO. Long. 43° 10′ W.

Year.	Magnetic dip or inclination.		Authority.	
			Observer.	Where recorded.
	°			
1817	—14.70		Freycinet	Becquerel's Traité du Magnetisme, 1846.
1820	—14.72		do	Do.
1821	—15.43		Rumker	Do.
1826	—14.07		King	Phil. Trans. Royal Society, 1877.
1827	—14.58		Lütke	Do.
1830	—13.58		Erman	Do.
1832	—13.62		Fitz Roy	Do.
1836	—12.90		Beechey	Do.
1837	—13.32		Du Petit Thouars	Do.
1838	—13.40	13.00	Sulivan	Do.
		13.02	do	Do.
		13.93	do	Do.
		13.62	do	Do.
1839	—13.12	13.08	do	Do.
		13.16	do	Do.
1847	—12.28		"Rattlesnake"	Do.
1852	—12.62		"L'Eugenia"	Swedish Magnetic Survey.
1857	—11.80		Novara Expedition	Phil. Trans. Royal Society, 1877.
1866	—11.78		Harkness	Do.
1881	—12.13		Van Rijckevorsel	Magnetic Survey of Eastern Part of Brazil.
1882.7	—12.00		Lieutenants Barnaud and Barnadières, Fr. N.	Annales Hydrographiques, 1884.
1887.8	—11.58		Lieut. Roujon, Fr. N.	Annales Hydrographiques, 1888.
1896	—12.92		Lieut. Schwerer, Fr. N.	Annales Hydrographiques, 1896.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1817	—14.70	—15.30	+0.60	0.3600	
1820	—14.72	—14.89	+0.17	0.0289	
1821	—15.43	—14.87	—0.56	0.3136	
1826	—14.07	—14.21	+0.14	0.0196	
1827	—14.58	—14.10	—0.48	0.2304	
1830	—13.58	—13.79	+0.21	0.0441	
1832	—13.62	—13.59	—0.03	0.0009	
1836	—12.90	—13.24	+0.34	0.1156	
1837	—13.32	—13.15	—0.17	0.0289	
1838	—13.40	—13.07	—0.33	0.1089	Probable error of a single observation = ± 14′.
1839	—13.12	—12.99	—0.13	0.0169	
1847	—12.28	—12.46	+0.18	0.0324	
1852	—12.62	—12.20	—0.42	0.1764	
1857	—11.80	—12.01	+0.21	0.0441	
1866	—11.78	—11.83	+0.05	0.0025	
1881	—12.13	—11.97	—0.16	0.0256	
1882.7	—12.00	—12.02	+0.02	0.0004	
1887.8	—11.58	—12.23	+0.65	0.4225	
1896	—12.92	—12.68	—0.24	0.0576	
				2.0293	

Empirical equation for determining the inclination for any year: $I = -11^\circ.81 - 0.0009\,(t - 1870) - 0.00126\,(t - 1870)^2$.

Lat. 31° 15′ N. SHANGHAI. Long. 121° 29′ E.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1843........	+44.75	Sir E. Home........................	Report for 1876 of the Zi-Ka-Wei Observatory.
1858........	+45.35	Novara expedition..............	Phil. Trans. Royal Society, Part I, 1875.
1872.3	+46.24	Shadwell............................	Phil. Trans. Royal Society, Part I, 1877.
1873.3	+46.32	.... do..............................	Do.
1875.5	+46.26	Jesuit missionaries	Le Magnétisme Terrestre à Zi-Ka-Wei, Chine, par Marc Dechevrens, S. J., Directeur de l'Observatoire.
1876.5	+46.23	.... do..............................	Do.
1877.5	+46.23	.... do..............................	Do.
1878.5	+46.22	.... do..............................	Do.
1879.5	+46.25	.... do..............................	Do.
1880.5	+46.27	.... do..............................	Do.
1881.5	+46.28	.... do..............................	Do.
1882.5	+46.30	.... do..............................	Do.
1883.5	+46.30	.... do..............................	Do.
1884.5	+46.32	.... do..............................	Do.
1885.5	+46.30	.... do..............................	Do.
1886.5	+46.28	.... do..............................	Do.
1887.5	+46.27	.... do..............................	Do.
1888.5	+46.23	.... do..............................	Do.
1889.5	+46.25	.... do..............................	Do.
1890.5	+46.19	.... do..............................	Do.
1891.5	+46.10	.... do..............................	Do.
1892.5	+46.12	.... do..............................	Do.
1893.5	+45.99	.... do..............................	Do.
1894.5	+46.01	.... do..............................	Do.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1843........	+44.75	+44.63	+0.12	0.0144	
1858........	+45.35	+45.67	−0.32	0.1024	
1872.3	+46.24	+46.18	+0.06	0.0036	
1873.3	+46.32	+46.20	+0.12	0.0144	
1875.5	+46.26	+46.24	+0.02	0.0004	
1876.5	+46.23	+46.24	−0.01	0.0001	
1877.5	+46.23	+46.26	−0.03	0.0009	
1878.5	+46.22	+46.26	−0.04	0.0016	
1879.5	+46.25	+46.27	−0.02	0.0004	
1880.5	+46.27	+46.27	+0.00	0.0000	
1881.5	+46.28	+46.27	+0.01	0.0001	
1882.5	+46.30	+46.27	+0.03	0.0009	
1883.5	+46.30	+46.27	+0.03	0.0009	Probable error of a single observation = ± 2′.4.
1884.5	+46.32	+46.25	+0.07	0.0049	
1885.5	+46.30	+46.25	+0.05	0.0025	
1886.5	+46.28	+46.24	+0.04	0.0016	
1887.5	+46.27	+46.23	+0.04	0.0016	
1888.5	+46.23	+46.21	+0.02	0.0004	
1889.5	+46.25	+46.19	+0.06	0.0036	
1890.5	+46.19	+46.17	+0.02	0.0004	
1891.5	+46.10	+46.15	−0.05	0.0025	
1892.5	+46.12	+46.12	+0.00	0.0000	
1893.5	+45.99	+46.10	−0.11	0.0121	
1894.5	+46.01	+46.07	−0.06	0.0036	
				0.0733	

Empirical equation for determining the inclination for any year: $I = 46°.13 + 0.0251\,(t - 1870) - 0.00112\,(t - 1870)^2$.

Lat. 1° 18′ N. SINGAPORE. Long. 103° 51′ E.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1837........	—12.48	"La Bonite"	Phil. Trans. Royal Society, 1875.
1841........	—12.72	Capt. C. M. Elliot................	Magnetic Observations at Singapore.
1842........	—12.70	.... do..................................	Do.
1843........	—12.68	.... do..................................	Do.
1844........	—12.65	.... do..................................	Do.
1845.2	—12.70	.... do..................................	Do.
1846........	—12.92	.... do..................................	Phil. Trans. Royal Society, 1875.
1848........	—12.97	.... do..................................	Magnetic Observations at Singapore.
1853........	—13.20	"L'Eugenie"	Annalen der Hydrographie, 1877.
1874.2	—13.25	Shadwell	Phil. Trans. Royal Society, 1877.
1875.1	—13.33	.... do..................................	Do.
1876........	—13.11	Van Rijckevorsel................	Trans. Royal Academy of Sciences, Amsterdam, 1880.
1890.5	—14.45	"Dubourdieu"....................	Letter from British Hydrographer, dated December 13, 1896.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1837........	—12.48	—12.74	+0.26	0.0676	
1841........	—12.72	—12.73	+0.01	0.0001	
1842........	—12.70	—12.73	+0.03	0.0009	
1843........	—12.68	—12.73	+0.05	0.0025	
1844........	—12.65	—12.73	+0.08	0.0064	
1845.2	—12.70	—12.74	+0.04	0.0016	
1846........	—12.92	—12.75	—0.17	0.0289	Probable error of a single observation = ± 9′.
1848........	—12.97	—12.76	—0.21	0.0441	
1853........	—13.20	—12.82	—0.38	0.1444	
1874.2	—13.25	—13.40	+0.15	0.0225	
1875.1	—13.33	—13.43	+0.10	0.0100	
1876........	—13.11	—13.47	+0.36	0.1296	
1890.5	—14.45	—14.19	—0.26	0.0676	
				0.5261	

Empirical equation for determining the inclination for any year: $I = -12°.78 - 0.0111\,(t - 1850) - 0.000587\,(t - 1850)^2$.

Lat. 15° 55′ S. ST. HELENA. Long. 5° 44′ W.

Year.	Magnetic dip or inclination.	Authority. Observer.	Authority. Where recorded.
	°		
1754	— 9.00	De la Caillé	Hansteen's Magnetismus der Erde, 1819.
1771	—13.00	C. G. Ekeberg	Do.
1825	—15.00	—15.05, Duperrey	Becquerel's Traité du Magnetisme, 1846.
		—14.94	On the Causes of Phenomenon of Terrestrial Magnetism, by Wilde.
1835	—18.00		Do.
1840	—21.25	Observatory	Phil. Trans. Royal Society, 1877.
1841	—21.43	do	Do.
1842	—21.42	do	Do.
1843	—21.75	do	Do.
1844	—21.93	do	Do.
1845	—21.92	do	Do.
1846	—22.23	do	Do.
1847	—22.62	do	Do.
1848	—22.82	do	Do.
1890.1	—31.18	E. D. Preston, assistant, United States Coast and Geodetic Survey.	Coast and Geodetic Survey Report for 1891.

Year.	Observed.	Computed.	O-C.	$\overline{O-C}^2$.	
	°	°			
1754	— 9.00	—10.17	+1.17	1.3689	
1771	—13.00	—10.90	—2.10	4.4100	
1825	—15.00	—17.60	+2.60	6.7600	
1835	—18.00	—19.46	+1.46	2.1316	
1840	—21.25	—20.44	—0.81	0.6561	
1841	—21.43	—20.65	—0.78	0.6084	
1842	—21.42	—20.85	—0.57	0.3249	Probable error of a single observation = ± 53′.
1843	—21.75	—21.06	—0.69	0.4761	Period = 600 years.
1844	—21.93	—21.26	—0.67	0.4489	
1845	—21.92	—21.47	—0.45	0.2025	
1846	—22.23	—21.67	—0.56	0.3136	
1847	—22.62	—21.90	—0.72	0.5184	
1848	—22.82	—22.12	—0.70	0.4900	
1890.1	—31.18	—31.34	+0.16	0.0256	
				18.7350	

Empirical equation for determining the inclination for any year: $I = -32°.95 - 20.37 \sin 0.6 (t - 1850) + 10.43 \cos 0.6 (t - 1850)$.

Lat. 33° 52′ S. SYDNEY. Long. 151° 12′ E.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1793.2	—60.01	Malaspina	Bode's Astronomisches Jahrbuch, 1828.
1824........	—62.31	Duperrey	Phil. Trans. Royal Society, Part II, 1877.
1831........	—62.86	—62.88, Bethane, 1831.........	Do.
		—62.85, Dunlop, 1831...........	Do.
1837........	—62.82	—62.82, Fitz Roy, 1836	Do.
		—62.80, Anonymous, 1837...	Do.
		—62.85, Wickham, 1838	Do.
1841........	—62.84	—62.98, H.M.S. Terror, 1841.	Do.
		—62.80, H.M.S. Erebus, 1841	Do.
		—62.87, H.M.S. Terror, 1841.	Do.
		—62.70, H.M.S. Erebus, 1841	Do.
1844........	—62.63	—62.62, H.M.S. Fly, 1842......	Do.
		—62.75, H.M.S. Fly, 1844......	Do.
		—62.52, H.M.S. Fly, 1845......	Do.
1849........	—62.73	H. M. S. Rattlesnake..........	Do.
1852........	—62.73	Kerr..	Do.
1858........	—62.68	Novara Expedition............	Do.
1865........	—62.66	Observatory	Letter dated July 6, 1896, from H. C. Russell, Esq., B. A., Government Astronomer, Sydney Observatory.
1874.4	—62.76	H. M. S. Challenger	Voyage of H. M. S. Challenger.
1890.8	—62.97	Lieut. Courmes, Fr. N.......	Annales Hydrographiques, 2d series, 2d vol., 1892.
1892........	—62.68	Observatory	Letter dated July 6, 1896, from H. C. Russell, Esq., B. A., Government Astronomer, Sydney Observatory.
1896........	—62.70	.... do..............................	Do.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1793.2	—60.01	—60.17	+0.16	0.0256	Probable error of a single observation = ± 11′.
1824........	—62.31	—62.11	—0.20	0.0400	
1831........	—62.86	—62.40	—0.46	0.2116	
1837........	—62.82	—62.61	—0.21	0.0441	
1841........	—62.84	—62.72	—0.12	0.0144	
1844........	—62.63	—62.79	+0.16	0.0256	
1849........	—62.73	—62.90	+0.17	0.0289	
1852..	—62.73	—62.94	+0.21	0.0441	
1858........	—62.68	—63.00	+0.32	0.1024	
1865........	—62.66	—63.02	+0.36	0.1296	
1874.4	—62.76	—62.98	+0.22	0.0484	
1890.8	—62.97	—62.64	—0.33	0.1089	
1892........	—62.68	—62.62	—0.06	0.0036	
1896........	—62.70	—62.49	—0.21	0.0484	
				0.8756	

Empirical equation for determining the inclination for any year: $I = -62°.97 - 0.0165\,(t - 1850) + 0.00056\,(t - 1850)^2$.

Lat. 17° 31′ S. TAHITI. Long. 149° 34′ W.

Year.		Magnetic dip or inclination.		Authority. Observer.	Where recorded.
		°			
1769	1774	—30.72	30.05	Cook	Hansteen's Magnetismus der Erde, Christiania, 1819.
1773.6		—29.72		Bayley	Walker's Terrestrial and Cosmical Magnetism.
1774.4		—29.97		do	Do.
1777.9		—29.78		do	Do.
1823	1826	—30.07	29.92	Duperrey	Phil. Trans. Royal Society, Part II, 1877.
1824		—29.27		Kotzebue	Do.
1830		—30.43		Erman	Do.
1835	1837	—30.23	29.83	Fitz Roy	Do.
1837		—29.12		Anonymous	Do.
1840		—30.17		Belcher	Do.
1859		—29.08		Friesach; Novara Expedition	Do.
1875.8		—29.97		H. M. S. Challenger	Voyage of H. M. S. Challenger.
1890.7		—29.33		Lieut. Courmes, Fr.N.	Annales Hydrographiques, 2d vol., 1892.

Year.	Observed.	Computed.	O-C.	$\overline{O-C}^2$.	
	°	°			
1774	—30.05	—29.71	—0.34	0.1156	Probable error of a single observation = ± 20′.
1826	—29.92	—29.70	—0.22	0.0484	
1837	—29.83	—29.70	—0.13	0.0169	
1859	—29.08	—29.70	+0.62	0.3844	
1875.8	—29.97	—29.70	—0.27	0.0729	
1890.7	—29.33	—29.69	+0.36	0.1296	
				0.7678	

Empirical equation for determining the inclination for any year: $I = -29°.70 + 0.00017 (t - 1850)$.

Lat. 33° 02′ S. VALPARAISO. Long. 71° 39′ W.

Year.	Magnetic dip or inclination.	Authority.	
		Observer.	Where recorded.
	°		
1790	—44.96	Malaspina	Bode's Astronomisches Jahrbuch, 1828.
1827	—39.10	Lütke	Phil. Trans. Royal Society, Part II, 1877.
1830	—40.19	King	Do.
1835	—38.05	Fitz Roy	Do.
1836	—37.08	Beechey	Do.
1837	—38.33	"La Venus"	Do.
1838	—38.72	do	Do.
1838	—38.20	do	Do.
1852	—36.80	Swedish Magnetic Survey	Annalen der Hydrographie, 1877.
1859	—35.67	Novara Expedition	Phil. Trans. Royal Society, Part II, 1877.
1866	—35.38	Harkness	Do.
1868	—34.38	H. M. S. Nassau	Do.
1875.9	—33.79	H. M. S. Challenger	Voyage of H. M. S. Challenger.
1875.9	—32.57	do	Do.
1893	—31.83	Lieutenant Mottez, Fr. N.	Annales Hydrographiques, 2d vol., 1893.

Year.	Observed.	Computed.	O–C.	$\overline{O-C}^2$.	
	°	°			
1790	—44.96	—44.76	—0.20	0.0400	
1827	—39.10	—39.73	+0.63	0.3969	
1830	—40.19	—39.31	—0.88	0.7744	
1835	—38.05	—38.60	+0.55	0.3025	
1836	—37.08	—38.45	+1.37	1.8769	
1837	—38.33	—38.32	—0.01	0.0001	
1838	—38.72	—38.17	—0.55	0.3025	Probable error of a single observation = ± 28′.
1838	—38.20	—38.17	—0.03	0.0009	Period = 400 years.
1852	—36.80	—36.32	—0.48	0.2304	
1859	—35.67	—35.40	—0.27	0.0729	
1866	—35.38	—34.56	—0.82	0.6724	
1868	—34.38	—34.33	—0.05	0.0025	
1875.9	—33.79	—33.49	—0.30	0.0900	
1875.9	—32.57	—33.49	+0.92	0.8464	
1893	—31.83	—32.04	+0.21	0.0441	
				5.6529	

Empirical equation for determining the inclination for any year: $I = -39°.99 + 8.41 \sin 0.9\,(t - 1850) + 3.45 \cos 0.9\,(t - 1850)$.

RÉSUMÉ OF THE EMPIRICAL EQUATIONS, TRANSFORMED TO FACILITATE THE COMPUTATION OF VALUES, TOGETHER WITH THE COÖRDINATE VALUES OF THE DECLINATION AND THE INCLINATION AT INTERVALS OF TE

…r Declination.	Epoch.	Probable error of single observation.	Assumed period.	Empirical expression for Inclination. I =	Epoch.	Probable error of single observation.	Assumed period.
°			Years.	° °			Years.
+ 278.8)	1713–1893	[illegible]'	240	− 21.67 + 9.81 sin (1.06 t + 14.5)	1768–1893	± 12'	350
+ 45.3)	1700–1890	23	600	− 12.32 + 23.58 sin (0.6 t + 154.3)	1754–1890	11	600
+ 17.2)	1726–1893	15	300	+ 43.66 − 0.0108 t − 0.000034 t²	1723–1891	8	
+ 247.8)	1605–1885	15	400	− 30.19 + 9.71 sin (1.2 t + 81.7)	1768–1895	29	300
+ 212.2)	1722–1889	12	450	+ 30.47 + 12.12 sin (0.8 t + 277.9)	1845–1895	8	600
267.2)	1700–1893	12	300	− 6.46 + 0.0495 t − 0.00076 t²	1790–1893	31	
+ 77.8)	1605–1890	23	700	− 49.11 + 8.75 sin (0.8 t + 211.3)	1751–1890	19	150
270.5)	1702–1885	18	360	+ 42.32 + 2.92 sin (1.2 t + 359.2)	1778–1895	60	300
256.6)	1709–1893	23	360	− 46.12 + 11.12 sin (0.9 t + 25.5)	1710–1893	38	400
264.3)	1700–1891	21	360	− 38.53 + 9.08 sin (1.1 t + 52.6)	1710–1884	3	327
+ 89.1)	1590–1891	46	530	+ 67.80 + 4.87 sin (0.75 t + 202.1)	1775–1890	17	150
318.75)	1726–1889	17	360	+ 51.76 − 0.0058 t + 0.00055 t²	1801–1887	14	
280.8)	1780–1887	15	450	+ 27.82 + 1.60 sin (0.9 t + 42.7)	1791–1895	18	400
1 t²	1817–1895	14		* + 10.31 − 0.0093 t + 0.00089 t²	1830–1893	17	
+ 211.8)	1783–1881	35	252	† + 18.26 − 0.0135 t + 0.00135 t²	1837–1895	5	
226.3)	1766–1890	8	360	+ 12.49 + 1.94 sin (1.0 t + 56.3)	1760–1893	35	360
358.3)	1790–1894	12	360	− 32.78 + 0.125 t − 0.00054 t²	1790–1893	12	
288.4)	1821–1891	14	300	+ 4.75 + 0.023 t + 0.000119 t²	1823–1891	11	
4.4)	1776–1885	13	200	+ 32.09 + 0.0071 t − 0.00061 t²	1790–1891	6	
350.7)	1815–1891	17	400	+ 5.27 + 8.29 sin (1.0 t + 115.5)	1768–1896	25	360
+ 0.3)	1779–1891	21	252	+ 61.54 + 0.99 sin (1.0 t + 48.3)	1779–1890	10	360
301.9)	1766–1893	17	360	− 56.23 + 10.64 sin (0.9 t + 351.0)	1760–1893	59	400
348.1)	1768–1888	25	360	* − 11.81 − 0.0009 t − 0.00126 t²	1817–1896	14	
0149 t²	1858–1884	2		* + 46.13 + 0.0251 t − 0.00112 t²	1845–1891	2	
244.1)	1824–1891	17	400	− 12.78 − 0.0111 t − 0.000587 t²	1837–1890	9	
68.2)	1610–1890	12	600	− 32.95 + 22.88 sin (0.6 t − 152.9)	1751–1890	53	600
+ 258.4)	1770–1880	10	320	− 62.97 − 0.0105 t + 0.00056 t²	1793–1896	11	
244.9)	1768–1878	14	360	− 29.70 + 0.00017 t	1769–1891	20	
270.8)	1709–1884	18	360	− 39.99 + 9.09 sin (0.9 t + 22.3)	1790–1893	28	400

…r Declination.	1720. D.	1720. I.	1730. D.	1730. I.	1740. D.	1740. I.	1750. D.	1750. I.	1760. D.	1760. I.	1770. D.	1770. I.	1780. D.	1780. I.	1790. D.	1790. I.	1800. D.	1800. I.	1810. D.	1810. I.	1820. D.	1820. I.	1830. D.	1830. I.	1840. D.	1840. I.	1850. D.
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
+ 278.8)							− 8.26		− 8.51		− 8.87	− 28.04	− 9.24	− 26.54	− 9.62	− 24.80	− 9.99	− 23.13	− 10.31	− 21.31	− 10.58	− 19.50	− 10.76	− 17.77	− 10.85	− 16.18	− 10.84
+ 45.3)							+ 7.13	+ 11.19	+ 8.52	+ 10.88	+ 9.92	+ 10.32	+ 11.33	+ 9.49	+ 12.73	+ 8.43	+ 14.10	+ 7.16	+ 15.39	+ 5.67	+ 16.72	+ 3.97	+ 17.93	+ 2.11	+ 19.06	+ 0.06	+ 20.11
+ 17.2)	− 3.35	+ 44.49	− 3.74	+ 44.47	− 4.03	+ 44.44	− 4.22	+ 44.30	− 4.28	+ 44.35	− 4.22	+ 44.30	− 4.06	+ 44.25	− 3.78	+ 44.19	− 3.40	+ 44.12	− 2.95	+ 44.04	− 2.42	+ 43.95	− 1.87	+ 43.87	− 1.29	+ 43.77	− 0.73
+ 247.8)							+ 2.69		+ 2.22	− 40.19	+ 1.73	− 38.59	+ 1.21	− 36.58	+ 0.74	− 34.56	+ 0.27	− 32.60	− 0.17	− 30.80	− 0.56	− 29.24	− 0.91	− 27.99	− 1.20	− 27.08	− 1.43
+ 212.2)							+ 3.73		+ 3.25		+ 2.77		+ 2.28		+ 1.80		+ 1.31		+ 0.90		+ 0.50		+ 0.11		− 0.17	+ 18.36	− 0.43
267.2)															− 9.01	− 12.17	− 9.44	− 10.83	− 9.81	− 9.66	− 10.11	− 8.62	− 10.38	− 7.75	− 10.54	− 7.03	− 10.61
+ 77.8)							+ 18.96	− 42.84	+ 20.46	− 43.75	+ 21.90	− 44.78	+ 23.25	− 45.88	+ 24.51	− 47.04	+ 25.06	− 48.21	+ 26.67	− 49.46	+ 27.56	− 50.68	+ 28.29	− 51.86	+ 28.86	− 52.99	+ 29.28
270.5)									− 5.55		− 6.08	+ 39.12	− 6.60	+ 39.41	− 7.09	+ 39.53	− 7.53	+ 39.77	− 7.90	+ 40.12	− 8.21	+ 40.57	+ 8.13	+ 41.10	− 8.57	+ 41.67	− 8.61
256.6)							− 12.23	− 56.46	− 12.81	− 55.58	− 13.42	− 54.18	− 14.05	− 53.19	− 14.64	− 51.72	− 15.21	− 50.13	− 15.73	− 48.14	− 16.19	− 46.71	− 16.57	− 44.96	− 16.86	− 43.26	− 17.05
264.3)							− 10.78	− 46.18	− 11.27	− 45.10	− 11.76	− 43.79	− 12.25	− 42.28	− 12.72	− 40.64	− 13.15	− 38.91	− 13.53	− 37.17	− 13.85	− 35.49	− 14.10	− 33.91	− 14.28	− 32.50	− 14.37
+ 89.1)							+ 17.13		+ 18.72		+ 20.21	+ 70.79	+ 21.60	+ 70.26	+ 22.81	+ 69.69	+ 23.91	+ 69.10	+ 24.83	+ 68.47	+ 25.57	+ 67.80	+ 26.10	+ 67.20	+ 26.44	+ 66.57	+ 26.57
318.75)							− 5.30		− 5.78		− 6.10		− 6.35		− 6.50		− 6.56	+ 53.12	− 6.52	+ 52.87	− 6.39	+ 52.42	− 6.17	+ 52.10	− 5.87	+ 51.87	− 5.49
280.8)															− 0.69	+ 26.92	− 0.83	+ 27.63	− 0.96	+ 28.35	− 1.04	+ 29.07	− 1.08	+ 29.75	− 1.09	+ 30.37	− 1.06
1 t²																			− 11.34		− 10.66		− 10.13	+ 42.10	− 9.75	+ 41.39	− 9.52
+ 211.8)													− 5.55		− 6.21		− 6.96		− 7.73		− 8.49		− 9.18	+ 50.38	− 9.77	+ 49.44	− 10.22
226.3)									+ 0.18	+ 9.75	+ 0.10	+ 10.50	+ 0.01	+ 11.32	− 0.08	+ 12.17	− 0.18	+ 13.03	− 0.28	+ 13.88	− 0.38	+ 14.68	− 0.48	+ 15.11	− 0.56	+ 16.06	− 0.64
358.3)															− 13.71	− 42.22	− 13.31	− 40.38	− 12.87	− 38.64	− 12.34	− 37.02	− 11.72	− 35.50	− 11.07	− 34.08	− 10.40
288.4)																					− 9.10	+ 4.17	− 9.17	+ 4.34	− 9.17	+ 4.53	− 9.00
4.4)											− 7.43		− 7.71		− 7.87	+ 29.46	− 7.41	+ 30.22	− 7.81	+ 30.83	− 7.58	+ 31.33	− 7.26	+ 31.75	− 6.86	+ 31.96	− 6.43
350.7)										+ 8.95		+ 10.18		+ 11.26		+ 12.10		+ 12.85	+ 3.00	+ 13.31	+ 4.21	+ 13.52	+ 5.56	+ 13.49	+ 6.98	+ 13.20	+ 8.44
+ 0.3)											− 5.74	+ 63.02	− 5.98	+ 63.17	− 6.02	+ 63.31	− 5.85	+ 63.51	− 5.19	+ 63.68	− 4.95	+ 63.85	− 4.27	+ 64.01	− 3.49	+ 64.15	− 2.66
301.9)									− 21.38	− 66.87	− 22.10	− 66.74	− 22.71	− 66.35	− 24.20	− 65.71	− 23.55	− 64.84	− 23.75	− 63.75	− 23.79	− 62.49	− 23.69	− 61.06	− 23.43	− 59.52	− 23.03
348.1)									− 6.86		− 7.04		− 6.96		− 6.62		− 6.00		− 5.16	− 16.30	− 4.11	− 14.92	− 2.87	− 13.79	− 1.49	− 12.91	− 0.02
0149 t²																									+ 1.93	+ 44.47	+ 1.01
244.1)																					− 1.39		− 1.71	− 12.79	− 1.97	− 12.73	− 2.19
68.2)							+ 10.18	− 10.09	+ 11.80	− 10.34	+ 13.39	− 10.85	+ 14.94	− 11.58	+ 16.39	− 12.54	+ 17.74	13.73	+ 19.00	− 15.15	+ 20.13	− 16.75	+ 21.14	− 18.51	+ 21.99	− 20.46	+ 22.67
+ 258.4)															− 8.14	− 59.73	− 8.74	− 60.61	− 9.03	− 61.35	− 9.26	− 61.96	− 9.16	− 62.12	− 9.61	− 62.76	− 9.70
244.9)									− 1.81	− 29.72	− 5.13	− 29.71	− 5.47	− 29.71	− 5.81	− 29.71	− 6.14	− 29.71	− 6.46	− 29.71	− 6.78	− 29.71	− 7.02	− 29.70	− 7.21	− 29.70	− 7.41
270.8)															− 14.24	− 44.76	− 14.61	− 43.19	− 15.06	− 42.15	− 15.36	− 40.74	− 15.61	− 39.31	− 15.72	− 37.89	− 15.76

…*ast* declination …terval of time …rd, minus when

Inclination of *north* end *below* the horizon is *positive*, *above* the horizon is *negative*; t expresses the interval of time reckoned from 1850; plus when forward and minus when backward.

* N. B.—In these cases t is reckoned from *1870* instead of *1850*.

† N. B.—In this case t is reckoned from *1875* instead of *1850*.

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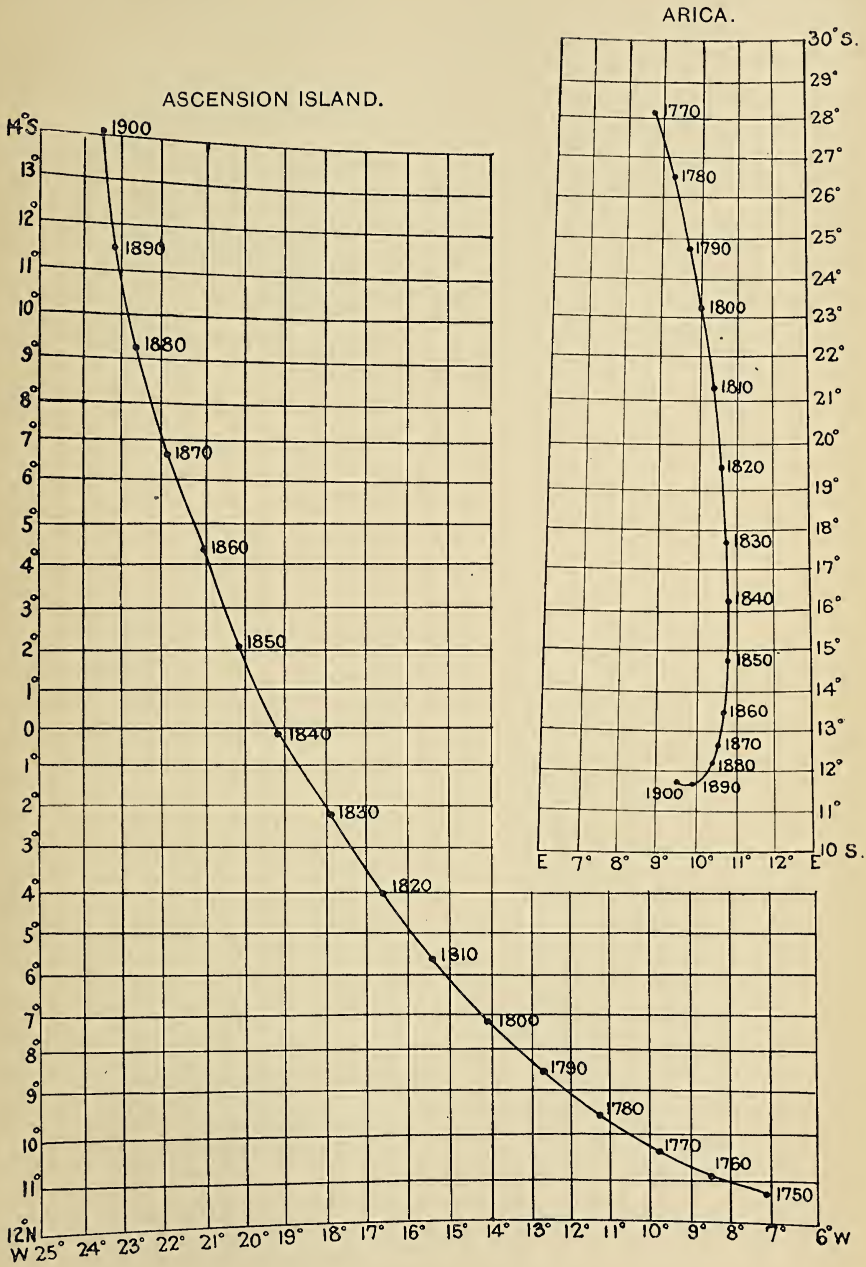
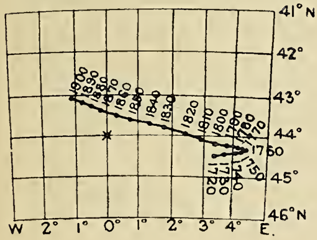

ARICA.
ASCENSION ISLAND.
1770
1780
1790
1800
1810
1820
1830
1840
1850
1860
1870
1880
1890
1900
30° S.
10 S.
E 7° 8° 9° 10° 11° 12° E
1750
1760
14°S
12°N
W 25° 24° 23° 22° 21° 20° 19° 18° 17° 16° 15° 14° 13° 12° 11° 10° 9° 8° 7° 6°W

BARBADOS (BRIDGETOWN).



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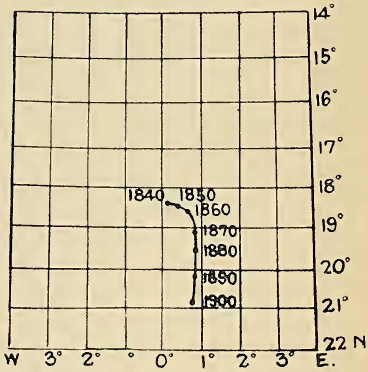

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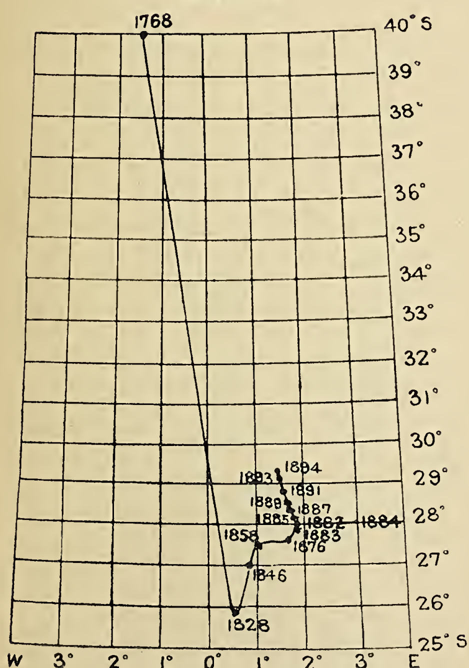
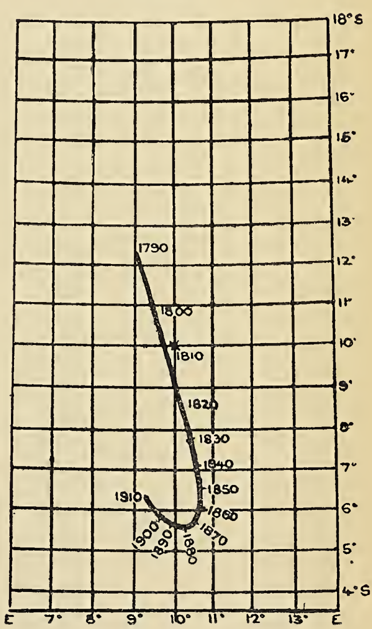


Plotted from observations.

CALLAO.



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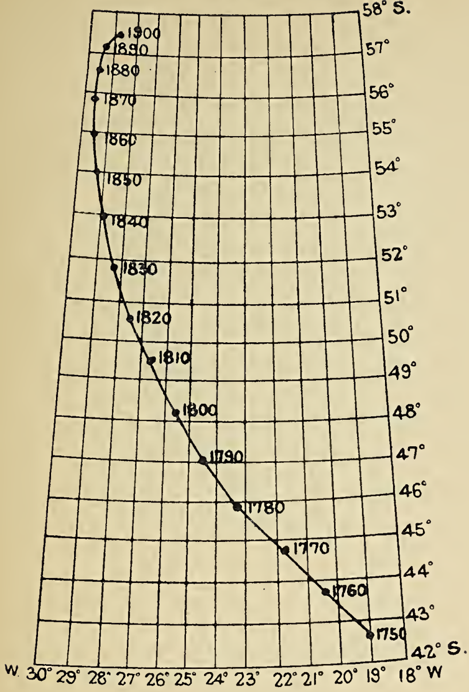

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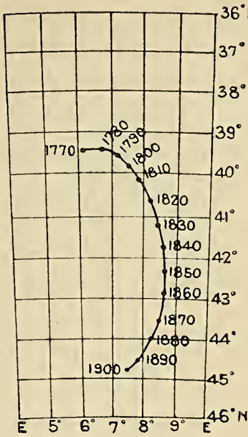

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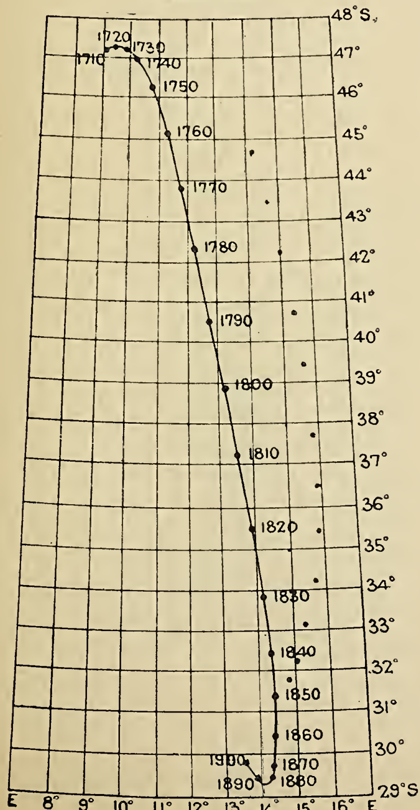

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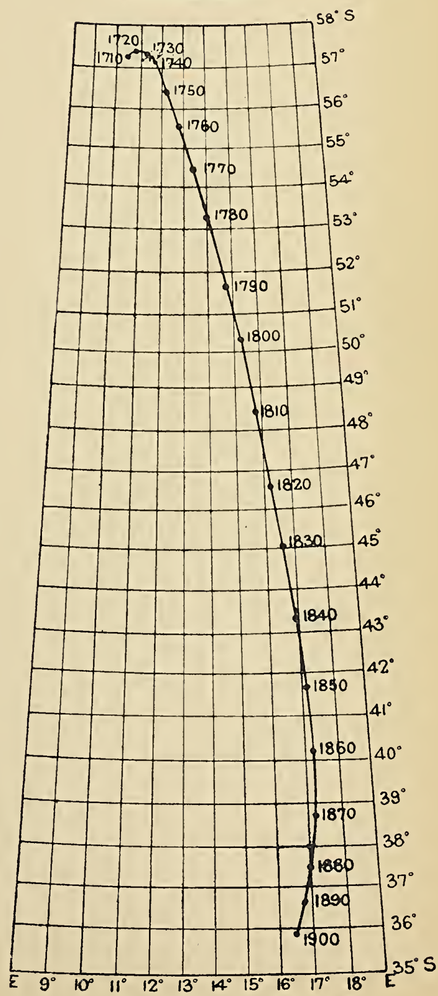
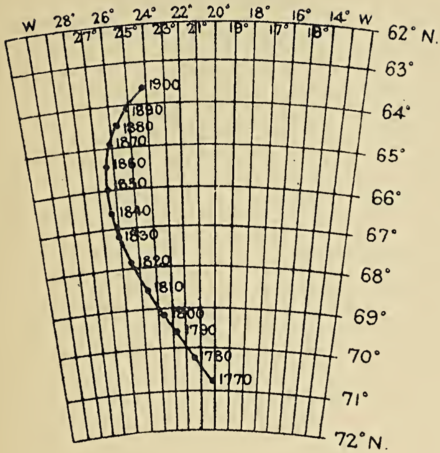


FAYAL, AZORES.



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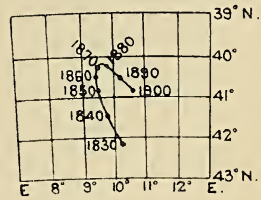

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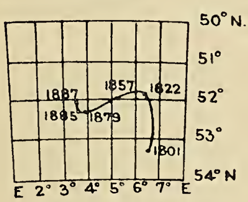

Plotted from observations.

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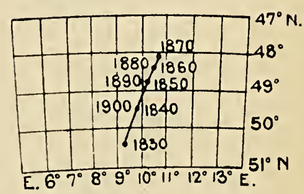

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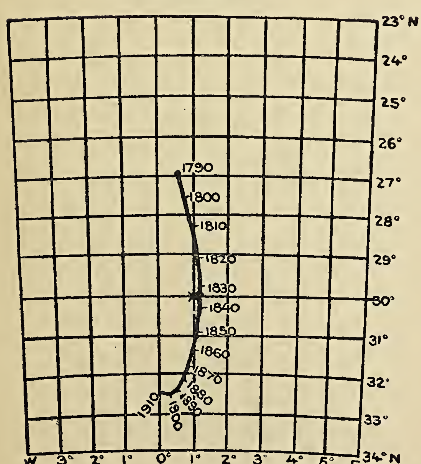

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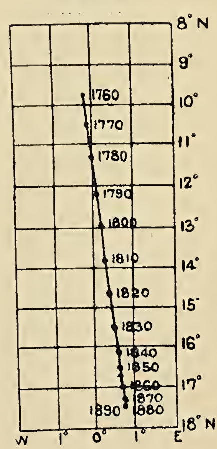

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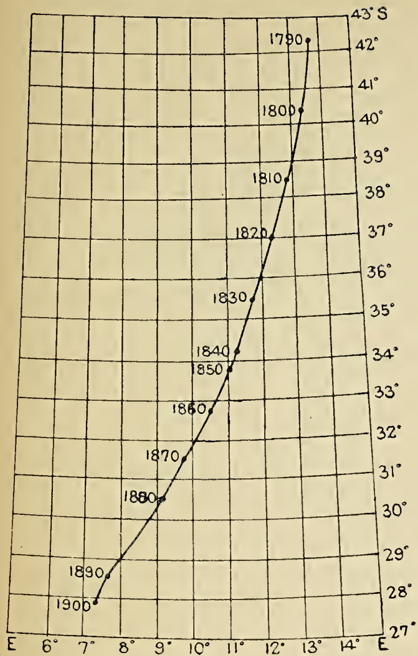

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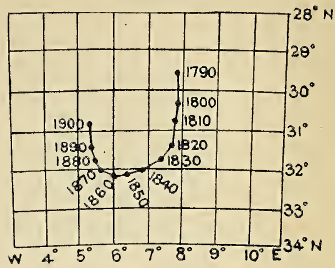

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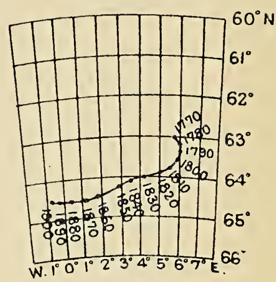

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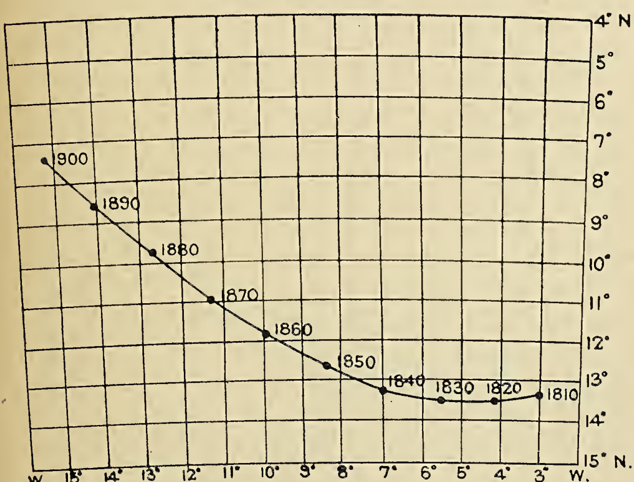

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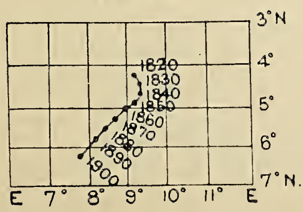

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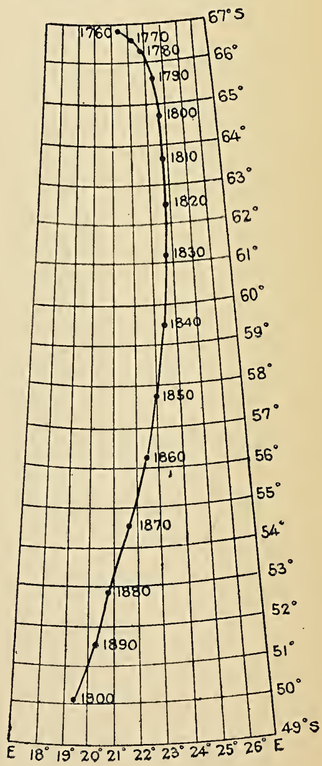

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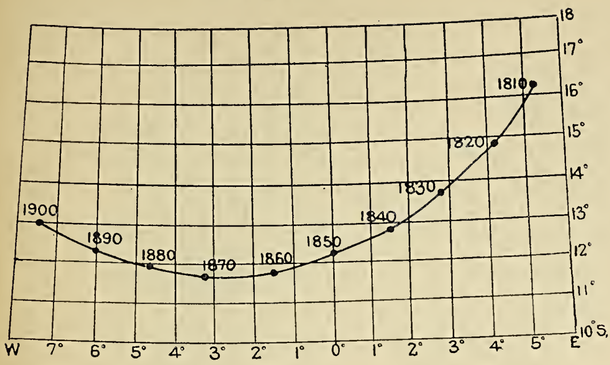

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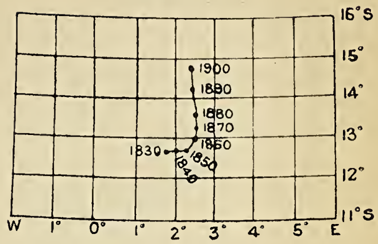

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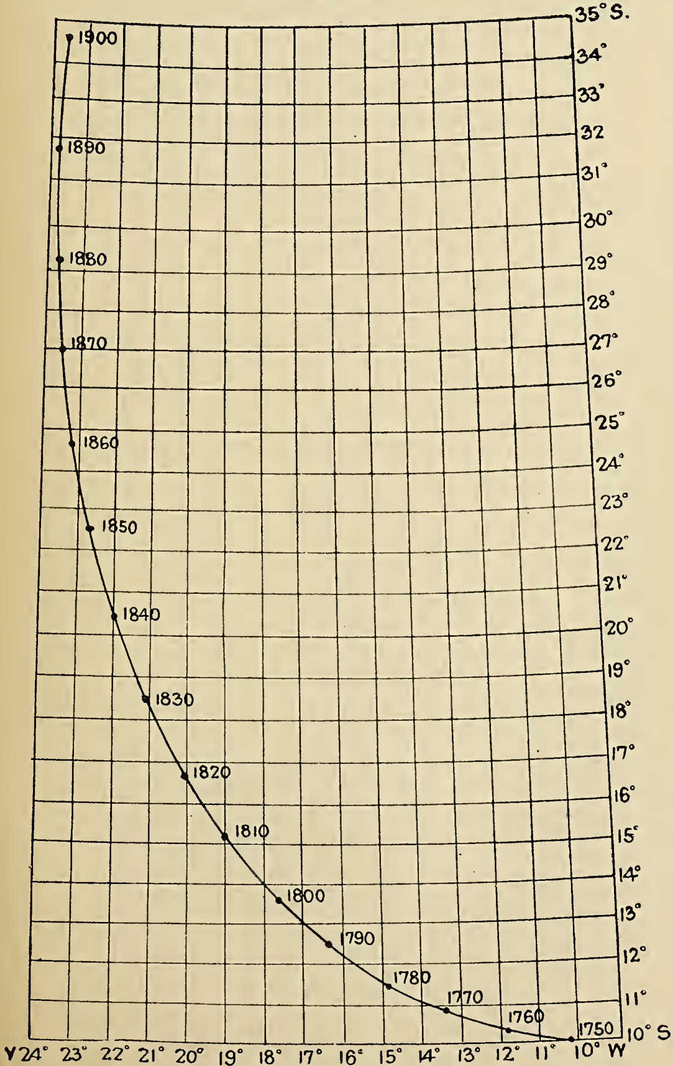

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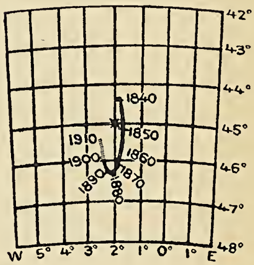

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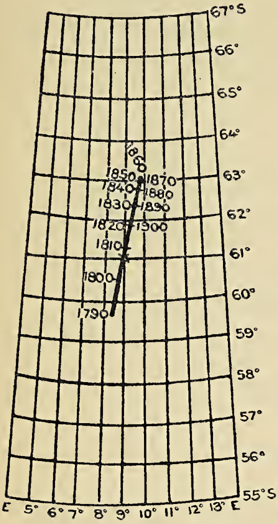

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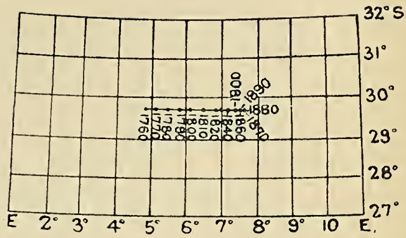

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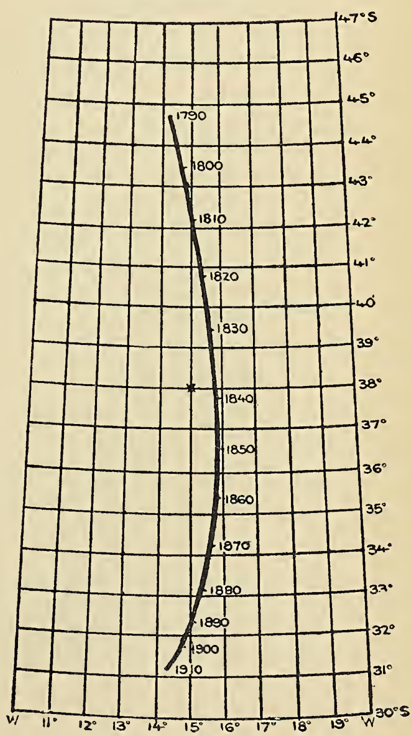

THE FUNCTION OF CRITICISM IN THE ADVANCEMENT OF SCIENCE

BY

Frank Hagar Bigelow

THE ANNUAL PRESIDENTIAL ADDRESS

DELIVERED

January 7, 1899

The history of the development of human knowledge towards its goal, perfection, which may also be regarded as the history of science itself, shows that there has been a gradual improvement in the number and precision of the facts known to man, in the mechanical and intellectual skill with which these are handled, and in the forecasting of the ultimate truths to which they point. This advancement in scientific knowledge has been compared to the gradual rise in the level of the sea upon the shore, which is marked by the ceaseless beat of the waves upon the rocks and sands, with the advance and the retreat of individual billows, and the bewildering swirl and foam of breakers and the returning undertow. We may not inappropriately compare the practical aspects of criticism to the waves of research which advance and retreat, in dependence upon the mighty ocean that impels it onwards, sometimes concealing with strife and controversy the grand harmony as it seeks its lawful expression.

Now, while it may be taken for granted that all educated persons, especially those who have attempted to add something to the sum of human knowledge, have general ideas

about criticism and what it attempts to do, yet I may be permitted to doubt that every one here has clearly thought out what the organic nature of the function is, and in what ways it operates to the best advantage. At least it may not be inappropriate to devote the time at my disposal to making some attempt to bring out the leading features of a subject so vital to the interests of science, with the hope of stimulating students to a more correct employment of this agency than has been uniformly the case in the past. It is proposed, therefore, after a few remarks intended to illustrate the misuse of criticism, to proceed with the statement of the canons of criticism and the recital of a few examples which illustrate them in the branches of science with which I happen to be partially acquainted. A complete exposition of my theme would involve the rehearsal of the entire range of scientific discovery since man entered upon the process of finding out things carefully and systematically.

The idea of criticism is apt to excite the thought of something very disagreeable, simply because no one enjoys the application of corrective measures to his lack of information, to his pride of reputation, and generally to his self-esteem or self-will. Ignorance brought home publicly and presumption exposed to rebuke are terrible weapons to punish those who break into Nature's great preserve by any other than the narrow way of labor that alone leads to ultimate truth; yet the genuine scientist cannot but rejoice to see his errors exposed, for few determined searchers in Nature's treasure-house have any satisfaction in following a barren vein or a phantom promise. Hence we may justly conclude that every true student is his own best and sharpest critic, so far as in him lies. Criticism is not something to be avoided or dreaded, if it is sound. It is rather one of those labor-saving devices that has fortunately been bestowed upon us to keep us from too much useless work.

On the other hand, what can be said that is too severe of the trash, which is falsely called criticism, that encumbers nearly every journal devoted to scientific information. There are two

classes of critics to whom no quarter should be shown, namely, the " omniscient critic " and the " professional critic," the man who knows all about all subjects, and the man who knowing little, yet criticises all things in heaven and earth. The former, that is the all-knowing critic, may really know some subject very well, but has conceived that this is guaranty that he may express equally positive views in many other fields of learning; the latter, the regular critic of all subjects, is usually equipped with sarcasm, innuendo, and a large phraseology. How often it has happened that men of power in one field of work have not modestly confined their criticism to that particular department of work. How common a thing it is for a man who has a reputation in some direction to become a sort of general authority and have all sorts of essays, papers, and treatises referred to him for his opinion. Now we all know very well that this sort of thing is practically impossible in the advancing specialization of science. The ramifications are too minute and too subtle for any one man even to keep posted on the bare facts in many directions. Hence this class of critics must necessarily go. The journals and magazines requiring the monthly quota of review material have been largely at fault in sustaining this class of criticism, but they ought to adopt the one obvious method of meeting the difficulty, namely, by sending for review the new paper to the best authority known, and then accept for publication his comments over his own signature. Let us do away with this anonymous kind of criticism. The best man writes sympathetically, he expresses valuable opinions, and generally courtesy and gentleness will mark his work. That is the kind of review which authors welcome, and it does not exasperate, nor does it discourage further endeavor. The harsh and destructive criticism is as seldom needed as a whip for a willing child; for surely, after a man has for years sought earnestly and painfully to secure a more correct knowledge of his subject, can anything be more distressing and unjust than to see his work caricaturized by a critic who plainly does not understand it—by one, for instance, who selects the wrong

case out of two or three which may occur, and proceeds to destroy that as if it really were the author's conception.

Then there is the other kind of critic just mentioned, the man who is really ignorant and yet makes his copy by writing something in general terms, or else in an entirely incorrect manner, about another man's production. Such men are not mathematicians, they are not philosophers; they may be general readers, but they do not possess the critical faculty of seeing things exactly as they are. We might spend our time in enlarging upon these faulty styles of criticism, and they would make very interesting reading, though perhaps too personal for comfort, but we hasten onwards to some exposition of that just, genuine, and noble criticism whose application to the advancement of science it is a pleasure to facilitate in every possible way.

We may arrive at a definition of the logical process of criticism, philosophically considered, by referring to the principle of identity—A is A, or A is not B. This is the ground of the intellectual process of judgment. Having prepared two or more concepts, through sense-perception or intuition, the mind advances by comparison, and the idea of identity or non-identity, to a judgment or affirmative proposition; out of a group of such identity judgments we possess the faculty to generalize these primary elements into laws and universal ideas, which are the final products of human intelligence. Concept, judgment, general law—these are the three stages in the gradual construction of knowledge. Now, criticism is essentially the exercise of the faculty of knowing in all these three stages, but especially it is that of judgment, which holds the central transitional place. We must know that the objects of knowledge are true and not false; we must group these objects by similarities and identities; we must perceive the features common to these groups in order to construct laws and theorems. Theories are the tentative and probable forecasts of the laws which may embrace many groups of identity judgments, and it is the dream of the human mind to rise at last to the central

unifying law, the attainment of which is the goal of philosophy. The comprehensive unit idea has not yet, except very vaguely, floated before the most exalted human mind. Science in its present stage is chiefly concerned with building up correct concepts, commonly called facts; progress has been made in the province of identity; and some working laws, holding good in limited realms of thought, have apparently been attained, but yet we can scarcely claim to be much better off than blindly groping after final truths.

Practical ideas about criticism can easily be drawn from this general analysis. Suppose some new fact or law is proposed, then the first test to be applied is whether it is *true* or *false;* the second is whether it is *new* or *old;* the third is its *place* in the general scheme of knowledge. If what is offered in evidence by an author can be shown to be *inaccurate, incorrect, or false* by its lack of harmony with other facts or pieces of evidence, by some internal inconsistency, or by its incompleteness, then it fails, and by just criticism it is thrown out. But, having passed this stage successfully, it is next necessary to examine its bearing upon other previously admitted parts of knowledge to discover whether it is *new* or is in reality *old*, being merely something presented in a different aspect, disguised perhaps unintentionally and unconsciously, but yet being merely a phase of some other product of experience. Finally, having been passed upon by criticism and believed to be *true* and *new*, then it is necessary to determine its dimensions, so to speak, its size, whether it is smaller than some more comprehensive law and is to be placed as a subordinate part of it, or whether it is larger and contains other laws within itself—that is to say, we must determine its rank in the hierarchy of ideas. These three canons of criticism, *truth*, *newness*, *rank*, corresponding as they do to the three forms of thought, *concepts*, *judgments*, *general laws*, respectively, are thus easily comprehended and should be consciously practiced by scientific critics; for we claim that criticism should become as much a function of science as the discovery of facts and laws, and indeed it is

here contended that this is the great intellectual process by which advancement can be profitably assured. The lack of system in criticism, the haphazard controversy, involving bitter feelings, slander, and errors of statement on the part of the critic, far less excusable than the honest but mistaken results of laborious investigation, should never have any place in science, properly so called. These questions should be put to himself by every searcher after truth and by every critic of other men's work:

1. Is the concept and the fact *true?*

2. Is it something *new*, or is it already known in some other aspect?

3. Is it *subordinate* or *superior* to the allied facts and laws with which it is compared?

The first thought which comes to mind regarding the practical operation of such critical canons is this, that with the growth of human knowledge it is becoming harder every year to be a sound critic in any department of knowledge because of the immense range and the tremendous catalogue of facts which one must acquire in order to be able to apply the first and the second canons of *truth* and of *newness* to any candidate for matriculation in the school of science. The extension is fast becoming so great that our individual specialization is beginning to make us quite incompetent critics, except in very narrow fields. Furthermore, many new ideas have their range legitimately in several adjacent departments, as, for instance, astronomy, geodesy, meteorology, terrestrial magnetism, and pure physics, so that the comprehensive minds who can conquer definitely these vast ranges of knowledge and are equipped for intelligible criticism must diminish in number. That is why the pseudo-critic already alluded to does so much harm by reason of his own lack of preparation in the premises. On the other hand, we may gain hope from the fact that the application of the third canon, of *rank,* is gradually building up sweeping incisive principles and laws so that a multitude of facts are already securely subordinated in their proper order. What a splen-

did power of hierarchy pertains to the Newtonian law of gravitation, to the mechanical equivalent of heat, to entropy, to potential and kinetic energy, to the principle of conservation of work energy, to chemical equivalents, to the electric and magnetic cross-connections. If the extension of the elements of knowledge threatens to overwhelm our powers of endurance, we may take refuge in the belief that the profoundly mysterious power of the mind, by which unification in laws of deeper intensity is going on *pari passu*, will be ultimately able to keep the scales of judgment and criticism evenly poised in a just equilibrium.

It is evident that the memory of the multitude of incidents which have occurred tempts one to relate many stories of faulty criticism, and thus to draw aside from the real object of this address, namely, to give a few examples of the sound criticism which has materially contributed to the advancement of science. However, before passing on to that part of the subject, one may be permitted to illustrate the erroneous use of the three principles which have been laid down for the guidance of critical efforts. Nothing is more common than for a critic to be wrong about his own comprehension of the facts in the case, and this may be partly due to a lack of complete information or to a tendency to jump to conclusions without sufficient preliminary study.

1. A traveler on the western arid plains found some hard balls lying on the ground about the size of a goose egg and coated with a white shell which contained a mass of tough grass, hair, and other loose material. Specimens were duly sent east for expert opinion as to their nature, with an account of the conditions under which they were discovered. The answer was returned that these balls were buffalo cuds which had become hardened by exposure. Nevertheless the same traveler afterwards saw some bugs—tumble-bugs he called them—who industriously formed little balls on the ground and then rolled them along till they had grown beyond their strength to move, having by that time acquired considerable size, when they were abandoned. So the balls never performed in the function of buffalo digestion.

2. A gentleman had a favorite tree in his yard which suddenly began to turn yellow at the very top, the trouble spreading rapidly downward and involving the entire foliage. An expert was called in to assign a cause for this disaster and suggested that the leaves had been killed by spraying too much with oil or tobacco. But the owner was able to state that he never had any apparatus for this purpose in his possession, and that certainly no poisonous material had been used on the tree in question.

These are instances of mistaken identity as to the primary facts and show violation of that canon of truth.

3. A pathetic case came into my own experience some years ago. A man sent for examination one of those curious results which are so plentifully derived from the loose reasoning of "planetary meteorology." It was contained on a diagram several yards in length, giving curves, orbits, conjunctions of all sorts of phenomena, and it was quite evident that much time had been expended in its preparation. It seemed to me proper to return some courteous comments in very general language and, as I supposed, entirely concealing my real opinion. Soon a letter arrived from the author thanking me for my favor and asking permission to use my name as an endorsement in the publication which was proposed. He stated that he was an invalid, had been practically confined to his bed for twenty years, and that my words contained the first encouragement he had received in all this time. One could not but pity the man, considering what it must have meant to him, but I declined to lend my name. The temptation was too strong, and it appeared all the same in his printed paper.

These are illustrations of criticism in which the facts are questioned as to their identity or truth. There is a class of erroneous criticism which comes from comparing two things not identical in their nature. Thus the comparison should be, A is B, but it was stated that A is C, whereas in reality B is not C. This occurs when, for instance, there is more than one possible case affording an explanation of the phe-

nomenon in question, and the application is made to the wrong case: (1) Several years ago an attempt was made to explain the peculiar curvature of the rifts of the solar corona which are photographed during an eclipse by comparing them with the lines of force surrounding a spherical magnet with uniform internal magnetism. A critic drew out his equations and the corresponding lines of force and claimed that they did not agree as was supposed. A brief examination of the formula revealed the fact that he had taken the companion case of a spherical magnet immersed in an independent external field, which changes the form of the curves near the surface. He simply applied the wrong case. (2) Another somewhat similar instance, but more complex in its details, came also to my notice. Three cases may occur in which the lines of force in a uniform magnetic field are distorted by placing a permeable substance within it, since the lines always seek the path of least resistance. The first is where a spherical solid as an iron sphere is placed in such a field, the lines taking on a system of curves determined by the strength of the field, the permeability and shape of the solid; secondly, if a spherical shell with a hollow interior is placed in the same field the lines assume similar but really different curves, and a part of them pass across the hollow (Barlow's Problem); if in the third case there is a permeable shell filled up with a substance impenetrable to magnetic lines, then the curves are different from either of the other cases, being more sharply exflected at the poles. It has been my conclusion that the earth, having a permeable shell and being filled with a material nucleus which entirely turns aside the lines of an external magnetic field, is comparable to the third case, and that in this way a number of observed phenomena find their explanation. A critic, however, carefully worked out the consequences of the second case and found that it did not agree with my exhibition of the phenomenon. It was contended that this criticism is inapplicable, because of mistaking the case which ought to be employed.

Mistaken identity is an exceedingly common error which

may befall any investigator, no matter how honest and intelligent, when groping in the dark after the hidden facts of nature, and it is no discredit to him that the advancement of science discloses this state of affairs. Indeed, so far the history of the progress of science has consisted chiefly in the superseding the views of one generation by those of another, which possesses wider knowledge and deeper experience derived from trial and practice. (1) For nearly a hundred years the problem has been before magneticians regarding the cause of the great disturbances which occasionally sweep over the earth's magnetic field and stir up currents of electricity in the crust of the earth, sometimes so strong as to paralyze the operations of the electric telegraph lines. It was always assumed that the disturbances and the ordinary diurnal variations of the needle had the same source. Careful investigation of the subject was made mathematically by reference to certain observations, and it was concluded that the sun as a magnet could not be depended upon to produce such effects without imposing excessive conditions. The development of two independent external magnetic fields surrounding the earth, having their seat respectively in two distinct physical conditions, as given by a discussion of the observations, has recently placed the problem in a new light; for it is shown that the disturbances belong to one of these fields, and the diurnal variations to the other, and that thus the early efforts to elucidate the subject were based on identifying two things which are really independent. Such is the criticism that has been recently advanced in this direction, namely, that the old position of magneticians fails because these two phenomena have different sources, while it was assumed that the same physical condition was behind each of them. (2) I have also ventured to make a criticism of about the same kind, though in connection with a much more difficult subject and one which may properly be held open for further discussion. It has been assigned by a very eminent authority as a reason for excluding the sun from consideration as an important agent in the disturbance of

the earth's magnetic field, that the work which it would be required to do to accomplish such an effect at the earth would be entirely impossible. This argument, if true, would cut us off from the only solution of this great problem which appears to be in the least hopeful; for it is shown to be a fact beyond controversy that the envelopes of the sun and the earth are continually passing through a series of complicated synchronous variations. Now, something must connect them. What is it? If the proposition is true that the sun's work must be excessive, and that therefore there is no connecting bond, then the problem is well-nigh hopeless. But we cannot yield to this view without further examination. The result of analysis is that there are three fundamental cases for consideration:

1. The electrostatic case, magnetic energy vanishing.
2. The magnetic case, electrostatic energy vanishing.
3. Joule's heat, electrostatic and magnetic energy.

It takes more work to adjust the variations of the energy due to electric currents when propagated through an electrostatic field than when transmitted in a magnetic field; hence if the sun has a variable magnetization, due to magnetic masses or electric-current systems passing from one state of equilibrium to another, the static electric field would require much more work than the polar magnetic field for these operations. To charge the electrostatic field from the sun to the earth is a tremendous undertaking, but the magnetic field, on the other hand, so reacts upon the source sustaining it as to require a minimum of work. The criticism is that the sun presents an instance of the second case and not of the first, as has been implied in the mode of thought heretofore presented.

These examples must serve to explain the first canon of criticism on the truth or falseness of the subject-matter. They have been introduced on the negative side rather than on the positive to explain some of the principal causes of the failure of critical studies. There are innumerable cases which might have been adduced to show how false facts,

false arguments, and imperfect laws have been thrown out from further consideration by science, and in which work the critics have done good service. There are two points which ought to be mentioned regarding the pseudo-scientist and the pseudo-critic before passing on to the next division of the subject: (1) What ought to be done with those crude scientists commonly called cranks, and their rude productions? The journals, and especially the press, abound with specimens of misapplied information, half-truth propositions, and generally unscholarly productions which may possibly impose upon the less cultivated class of readers. What is the best course to pursue? The temptation is to show them up and expose the false science beneath their words. Many have tried this process, but almost invariably the result has been the increased disgust of the scientific critic, who finds his opponent a good thrower of mud. His effort has resulted in a wider advertisement of the author's feeble ideas, and generally in the belittlement of true science. Undoubtedly the best policy is to let such men and all their works alone. If the ideas are of science, they will live; if not, they will die of themselves, and the world will be richer for the lack of the controversy. (2) What should be done when a true scholar is vehemently attacked, his views misinterpreted, and his reputation assailed? Some of our great men have adopted the course of never replying to such criticisms. They refuse absolutely to be drawn into any controversy, and prefer to suffer such injury rather than to be parties to any strife. Indeed, the unhappy heart burnings which have been engendered by scientific wranglings are so notoriously unprofitable, so productive of bitterness and estrangement, that strong men generally prefer to bear patiently these attacks than to be concerned in a story of discord which may be remembered longer than their otherwise good works. What a tale of woe could be gathered together in exemplification of this evil of scientific contention, and how many of them are readily recalled from our recollection of the history of science! There comes a time, however, when even the

lion should be roused, and then let us say that he should smite and not spare his false critics. Let the victory be complete.

We now pass to comment briefly on the second canon of identity, namely, whether the material is *new or old*. This is a precept which is becoming of increasing importance as the matter of scientific investigation accumulates, and with serious acceleration as time goes on. The immense mass of papers which must be examined before it is safe to pronounce a thing new in any subject is already becoming a source of anxiety to students. It is indeed the primary cause of the specialization now going on so rapidly, by which one man becomes an expert in a very limited field of work, but at the same time undergoes a process of isolation from his fellow-workers. It is perhaps necessary to submit to this accumulation of literature, because the human mind seems capable generally of only relatively small improvements at a time upon the work of predecessors, except in the rare instance of a genius being produced by the grand process of nature. Sometimes a vein is falsely exploited, sustained by the pretension of novelty and the desire to acquire a reputation, as when an author deliberately gives a well-known subject some slight twist, which persists throughout his exposition, while in reality the work contains no genuine new contribution to science. Also several men may have been working quite independently of one another and thus have brought forth similar results by means of different courses of procedure. At any rate, we can all see that the necessity of a scientific clearing-house is becoming essential not only for the convenience, but also for the real progress of science. There is need that in the subjects which have been practically cleared up there should be some authoritative statement regarding the final product of such investigations. Some attempt has been made towards this in two or three directions: (1) by means of the short summaries which certain journals of substantial purpose are publishing; (2) by the institution of congresses or conferences of specialists, who shall pronounce re-

garding certain definite subjects and be responsible for tables of constants, formulæ, as well as nomenclature. The very growth, however, of knowledge makes the task set for the standard journals increasingly difficult, because the reference summaries are meager and there must necessarily be an immense and increasing number of them. The work of our congresses or international committees is also unsatisfactory, because the labor of bringing many men to the same point of view regarding intricate questions is very great, and, indeed, so impracticable that in fact only few advanced problems, and usually only simple questions, can be treated in this way.

In my judgment, the best plan to pursue would be for experts to train themselves thoroughly in special directions, so that they can study up, digest, and classify certain branches of knowledge once for all, and thus leave to their successors all the real information there is, expressed in short space and in language recognized as standard. If this generation has been prolific of a multitude of research men, the time may not be far distant when advanced work will be limited to the few who have developed special knowledge and peculiar instinct for such progress, and when, simultaneously, a number of students shall unify and simplify to the utmost the real residuum of facts and laws. For this latter purpose we need first of all a standard international system of notation in mathematics and physics, by which it will become perfectly easy to pass from one man's writing to another's, so far as the use of coördinate axes, letters, and symbols to represent fixed quantities and relations are concerned. I have taken the trouble, indeed it has been a necessity for me to do so, to rearrange the symbols in my texts on meteorology and terrestrial magnetism in a uniform notation, to the great assistance of scholarship and pleasure in studying these subjects; for there is nothing more annoying than to acquire the ideas of one author in certain equations, and then on passing to another author who has written on parallel lines to find the same ideas and facts expressed in terms just enough different to make every equation and combination

look strange. It is also a surprise, after these subjects in a half a dozen books are reduced to one notation, to find how widespread the tendency is to go over the same ground again and again and yet with no real advance beyond suggestions as to minor details, which occur incidentally and only as subordinate aspects of the same truth.

Thus we find in (1) Barometry the attempt to put Laplace's equation in a dozen different forms, which neither advance in any respect the real subject of the variation of the air pressures with the height, while in fact all these can well be summarized in one system, such as the International Committee proposed; in (2) the Thermodynamics of the atmosphere, the fundamental relations are capable of being stated in one comprehensive scheme, which shall supplant all the papers now referred to, and wherein there is much repetition of work; in (3) Terrestrial Magnetism there are a half a dozen schemes of coördinates and notations now afloat, whereas by reference to three standard canons the entire subject can be made to read as one; in (4) Electricity and Magnetism, what a diversity of formulæ have been derived from *Maxwell* on the one hand and from *Helmholtz* on the other, forming now the English and the German schools; in (5) Astronomy and Geodesy there is the same divergence of processes springing from the several works of the original investigators, which yet might be reduced to one simple and comprehensive system. It seems to me that we must soon have a clearing-house of these fundamental matters, carried out radically and comprehensively. Then all authors should write their works in the adopted system, on the penalty of not being published at all. Much pretentious new knowledge will thus be found to be old, and all recognized advances will be substantial.

We must hasten over the second canon of newness and oldness, to spend the rest of our limited time on the fascinating topic suggested by the third case, namely, that of rank in the hierarchy of knowledge. This comprises the assignment of relative merit to those acquirements of science which as in-

dividual facts, laws, and theorems are sound, and have passed through the two antecedent stages of criticism. In illustration of this principle, it may be profitable to call attention to one of the most important and interesting struggles for supremacy that has arisen in the history of the development of science. There may be some features of this topic which are not sufficiently familiar to those who have never made a special study of these subjects, to make it particularly easy to understand fully the merits of this controversy, but probably the main features can be readily apprehended.

It may seem going very far apart to seek in the Ptolemaic system of astronomy, and the chemical theory of phlogiston, the remote beginnings of this modern strife, but that is apparently where it unconsciously began. There are three systems of astronomy which form the stages in the development of our modern science—the Ptolemaic, the Copernican, and the Newtonian. In the Ptolemaic system the stars and the planets were all regarded as having real motions about the earth, assumed itself to be at rest; in the Copernican system the sun is the center of motion, while the earth and the other planets rotate on their axes and revolve about it; in the Newtonian system all celestial motions are due to the operation of the one law of universal gravitation. In addition to the plausible account given of the observed motions of the stars and planets by the first system, its real strength consisted in the ancient difficulty of conceiving how the atmosphere, how men, and all other things could remain on a rapidly rotating sphere without sliding off. The fact which really broke down the theory was the incontestible one observed by sailors, that the surface of the sea was not flat, but that their ships descended from view. The heliocentric theory of Copernicus not only showed that the celestial motions could be as well accounted for by it as by the Ptolemaic system, and more simply, but that it also contained greater possibilities of knowledge. The observations of *Copernicus*, *Tycho*, and *Kepler*, giving rise to *Kepler's* three laws, culminated in the central law of gravitation, and *New-*

ton's three laws of motion. Herein the law of rank is superbly realized, and its crown, universal gravitation, is destined to endure at the head.

Another point that puzzled men so long was, How can a body keep moving about another continuously without some additional force to sustain the motion in its path? Only gradually did the great truth emerge, through the suggestions of *Leonardo da Vinci*, *Galileo's* law of falling bodies, and *Huyghens'* theory of central forces, till *Newton* was able to define it in the laws of inertia, composition of forces, and mutual action. The splendor of these conceptions excited the imagination of the best minds, not only to extend the sphere of observation but also the purely mathematical analysis of all sorts of mechanical problems. The great contribution of *Laplace*, *d'Alembert*, *Lagrange*, *Hamilton*, and many astronomers, whose names are immortal, have certainly carried out the promise of Newton's laws to splendid fulfillment. Along with the success attending these achievements, there grew up the conviction that the entire range of phenomena in the universe, great and small, can be finally reduced to some part of the theory of mechanics. With this object in view, all problems in physics, in chemistry, and even in mental psychology, have been attacked along the lines of mathematical mechanics. What shall we now say—with success? That is the very question to which I desire to direct your attention.

Along with the satisfactory solution of many problems which, though great in themselves, are only minor parts of a more comprehensive subject, the human mind has gradually gone onwards from the study of the operations of nature, as embodied in certain laws, to an investigation of what is behind the law itself—the forces, the energy, the ultimate substance, out of which the material world is built. For if the law of gravitation is known, what about the gravitating force itself—its origin, nature, and operation? What about molecular and chemical forces in themselves? What about the nature of heat energy, kinetic and potential energy, work

energy, electric and magnetic energy? What about the ether, the atoms, action at a distance or through a connecting medium? The mere mention of these modern questions is sufficient to recall the vague suspicion which has been recently overspreading the scientific world, that perhaps after all mathematical mechanics is going to fail of its ultimate mission. For I have only to remind you that the great modern masters, *Maxwell* and *Helmholtz*, definitely abandoned the use of the purely *mechanical* equations, and attained their advances by the employment of the more comprehensive *energy* equations; and also to note that their disciples, *J. J. Thomson*, *Heaviside*, *Hertz*, *Planck*, *Boltzmann*, *Helm*, and others, are working these problems from the energy point of view and not from the purely mechanical. The trouble has been two-fold. In the first place, the mathematical equations become too complicated for operation outside the province of simple geometrical points in their mutual interrelation; and in the second place, there is coming to realization the fact that the fundamental things of this universe are not so simple as the geometers would have them. The two laws of thermodynamics, with their expressions of conservation of energy, namely, the impossibility of creating energy or destroying it, and the impossibility of transforming energy except under certain definite conditions, have given rise to a new reach of knowledge apparently as high above the three Newtonian laws of motion, as these are above the Ptolemaic fear that man would slip off this earth if it were round. It is now about as difficult for us to perceive how it can be that the collision of gas molecules is maintained without the addition of some outside forces, as it was for the churchmen of Galileo's day to see how a planet can continue to circle about the sun without some outside force acting on it to push it along.

Let us now go back to our other starting point, the theory of phlogiston, and advance to the general point of view, namely, the struggle between mechanics and energetics, which we wish to more fully explain. The history of the

development of our ideas of energy, from the theory of phlogiston to the laws of intensity and capacity, is one of the most fascinating and instructive accessible to the student of science. The phlogistic theory, invented by *Stahl* at the end of the seventeenth century, was in vogue for about one hundred years, till *Lavoisier* overthrew it finally. It maintained the notion that every combustible substance contained an inherent principle which it lost during combustion. Hence all combustible substances are compounds. Charcoal, coal, sugar, flour, &c., are rich in phlogiston. The actual escape of flame from a burning substance as a visible something, the uncertainty of the nature of heat, and the idea that it is a form of imponderable matter, caloric, gave the theory its strength. Besides, no other theory was known which could take its place. Oxygen was dephlogisticated air because it was capable of taking more phlogiston from nitrous air, and therefore must itself contain less of the principle. Nitrogen was phlogisticated air because it could give up the burning material.

This theory fell under the blow which *Lavoisier* dealt it with his balances. He weighed his gas and found that what one lost on entering into chemical combination, the other gained in weight. He found that air consisted of a mixture of two gases, one of which could support combustion, while the other could not. He proved that water was a compound of hydrogen and oxygen, uniting in definite proportions. His opponents, the adherents of the phlogiston theory, *Priestly, Cavendish,* did their best to break the force of these experiments; but they never succeeded, and the theory perished with them, so far as phlogiston is concerned.

The similar theory of caloric had a life for nearly 50 years longer, till about 1845, when *Joule* by experiment proved the mechanical equivalence of heat and work; in other words, that heat, no more than the principle of combustion, is a substance. Having arrived at this negative proposition, it is not too much to say that after 50 years more of eager study we do not yet know what heat is, although we have discovered

much about the operations of nature roughly classified as heat. The story of this attempt to solve the main problem is worth repeating (Compare Energetik, *Helm*). The discovery that combustion must be ascribed to a process and not to a substance, and the later proof that heat is a process and not a substance, brought up the entire range of questions involved in natural process, and with them the study of the primary problems: What is force? What is energy? A long controversy arose over the proper measure of force. Some said, It is the motion generated, and hence where there is no motion there is no force. Others claimed that the acceleration of motion, the rate at which velocity of motion changes, is the true measure of force, and these still hold the field. *Helmholtz* defined energy as $E = \frac{1}{2} m v^2$ in 1847. It had already been surmised that heat is a form of motion. *Hobbes* thought that light and heat had a common origin in motion; *Locke* that heat is only motion; *J. Bernouilli* had the conception of the conservation of energy; *Daniel Bernouilli* suggested the kinetic theory of gases; Count *Rumford* boiled water by means of friction only; *Humphrey Davy* melted ice by rubbing two pieces over each other; *Fresnel* showed that light and heat are interchangeable; *Mohr* discussed the transformation of forces; *Lagrange* found the dynamic equation of a conservative system of forces. The practical mechanicians soon saw that the transformation of forces leads to the idea of the conservation of energy. *Poncelet* took as the measure of work a force operating through a given space and proved the principle of the transmission of work. This principle, work $= Fds$, is the ground of the energy conceptions, and from it comes the theorem of the mechanical equivalence of heat and work. *Robert Mayer*, 1842, laid down these concepts: "Energy is indestructible;" "energy has variable manifestations;" "energy is imponderable." He also distinguished clearly "potential and kinetic energy." These concepts have dominated the thought of the past 50 years, but recently we are trying to do away with the dis-

tinction between potential and kinetic energy, as an incomplete statement of a greater truth. *Rumford, Carnot, Mayer, Colding, Joule, Clausius,* and others have sought the mechanical equivalent of heat in various ways, and it turns out to be about 426.8 kilogram-meters or 777.9 foot-pounds for this latitude.

Helmholtz sought to ground a theoretic basis for the transformation of energy in the principle of the "impossibility of perpetual motion," and showed that the mode of transformation, such as a *Carnot* cycle, does not affect the result, but at first he was unsuccessful in arriving at an analytical expression. He then introduced the further principle of action and reaction, which is equivalent to limiting the operation of his cycles to central forces, and proved that rotations as well as translations must be taken into the account, and thus arrived at the famous theorem of the conservation of energy: "In conservative systems, the sum of the kinetic and the potential energies is a constant." *Helmholtz* made an application of his principle to magnetic, electric, and heat processes, but fell into another error, and his result met only with opposition, showing how hard it is even for a master mind to successfully grasp at the outset the truths of nature's operations. Another thread of the problem was worked out by *Carnot, Clausius,* and *Thomson,* culminating in the entropy theorem, which, coupled with the theorem of conservation, gives the two laws of thermodynamics. Stripped of all technicalities, the first or conservation law is, that energy cannot be created or destroyed by mechanical processes; the second or entropy law is, that the energy of a body can be transformed only from higher to lower states of intensity. The first law asserts that the sum total, or the energy of the universe, is constant; the second that the available useful energy of the solar system is diminishing in efficiency.

It cost much labor and effort to arrive at the true mathematical expression for the second law. The early investigators, *Carnot, Clayperon,* and *Horstmann,* did not emancipate their minds from the erroneous idea that heat is a substance,

caloric. *Carnot* knew that heat and work were transformable quantities, but, supposing that heat is an indestructible substance, he never went beyond the incorrect statement that heat is equivalent to the work done. He did not know about the entropy function, which connects the quantities of heat energy and work energy. *Clayperon* followed *Carnot's* error, and the differential equation which they adopted as fundamental is erroneous, since they supposed they were dealing with a true differential, which was not the case. *Carnot* introduced the fruitful idea of reversible and irreversible cycles; *Clayperon* used the indicator diagrams to measure the value of the work expenditure in a complete reversible cycle. To *Clausius* and *W. Thomson* (Lord Kelvin) belongs the credit of the discovery of the entropy function and the analytic form of the same. *Clausius* first used the word entropy in 1865, but the idea was complete in 1855. *Thomson* began his work on this subject with *Carnot's* idea, but in 1850 abandoned that view of the relation of heat and work. First he defined the absolute temperature, then he relinquished *Carnot's* statement that in doing work heat as a substance does not lose in quantity, but only in aspect, and accepted *Clausius,* proposition that heat is a molecular movement, which in doing work loses quantity as well as changes in aspect. *Carnot* had, however, this correct idea, that the kind of medium through which the work is done is not essential, but only the initial and final temperatures, for otherwise perpetual motion would be possible. *Clausius* admitted that the small changes in the intrinsic energy, the heat energy, and the work energy are not true differentials, but only small variations.

Thomson reaches the relation, $\frac{AW}{Q_2} = \frac{\theta_1 - \theta_2}{\theta_2}$ where A is the mechanical equivalent of heat;

W is the work performed;

Q_2 is the heat transformed at the higher temperature, θ_1,

θ_2 being the lower temperature.

There follows from this, $S = \int_{z_0}^{z} \frac{dQ}{\theta}. \qquad dQ = \theta dS.$

The expression, $dS = \frac{dQ}{\theta}$, is called the entropy law, and was put in its final form by *Planck.* It shows that the entropy must increase for a given expenditure of heat operating at a fixed temperature, or if the entropy is held constant, the temperature must be lower. Hence the entropy of the world tends towards a maximum, or the temperature of the world is running down towards a minimum. Since this formula applies only to *Carnot's* reversible processes, we find that for all irreversible processes the expression is $dQ < \theta dS$, and hence the complete expression of the second law of thermodynamics is $dQ \overline{\lesssim} \theta dS$. For the first law we have $dE \overline{\lesssim} \theta dS + dA$, where dE is the change in the intrinsic energy, θdS that in heat energy, and dA that from all other sources, the sign of equality holding for the reversible processes and the sign of inequality for the irreversible processes.

I may well apologize for going so far into technical expressions, but the importance of the conclusion in view is such that I beg your indulgence for a very few moments longer. When the principles suggested by the second law of thermodynamics are applied to the other processes of nature, it is found that nearly every region of phenomena falls under the same general form, and that taken together they make up one great principle, of which $dQ = \theta.dS.$ is the type. The following table is compiled from *Helm's* Energetik, 1898, and embraces heat, kinetic and potential mechanical energy, central and cyclic work, surface and volume energy, terrestrial and universal gravitation, frictional and chemical energy, electric and magnetic energy, electric and magnetic polarization:

Forms of energy.		Intensity.		Capacity.		Change in energy.
Q	Heat.	θ	Absolute temperature.	S	Entropy.	$dQ = \theta \,.\, dS.$
T	Kinetic energy.	x^1	Velocity.	mx^1	Force.	$dT = x^1 \,.\, d(mx^1).$
U	Potential energy.	V	Potential function.	m	Molar mass.	$dU = V \,.\, dm.$
A_o	Work (cyclic).	$2T$	Kinetic energy.	$log\ q$	Cyclic moment.	$dA_o = 2T \,.\, d\ log\ q.$
A	Work (central).	X	Force.	X	Distance.	$dA = X \,.\, dx.$
A_ω	Surface energy.	P_1	Surface tension.	ω	Surface.	$dA_\omega = P_1 \,.\, d\omega.$
A_τ	Volume energy.	P	Pressure.	τ	Volume.	$dA_v = P \,.\, d(-\tau).$
W	Terrestrial gravity.	h	Height.	gm	Weight.	$dW = h \,.\, d(gm).$
Z	Universal gravitation.	$\frac{M}{r}$	Potential.	m	Mass.	$dZ = \frac{M}{r} \,.\, dm.$
R	Friction.	υ	Velocity.	K	Resistance.	$dR = \upsilon \,.\, dK.$
C	Chemical energy.	Π	Chemical intensity.	M	Chemical mass.	$dC = \Pi \,.\, dM.$
E_e	Electric energy.	F	Electric tension.	ε	Electricity.	$dE_e = F \,.\, d\varepsilon.$
E_H	Magnetic energy.	Ω	Magnetic tension.	H	Magnetism.	$dE_H = \Omega \,.\, dH.$
D	Displacement.	J	Electric current.	i	Electric density.	$dD = J \,.\, di.$
B	Induction.	G	Magnetic current.	N	Magnetic density.	$dB = \Delta \,.\, dN.$

Lagrange's Law (energetics). $\frac{d}{dt}\left(\frac{\delta(T-U)}{\delta p'}\right) - \frac{\delta(T-U)}{\delta p} = P$, external force tending to increase p.

d'Alembert's Law (mechanics). $\int_{t_o}^{t_1} \Sigma(Xdx + Ydy + Zdz) = T_1 - T_o$, increase of energy.

I. Helmholtz's Law. $T + U = H =$ conservation of energy.

II. Intensity and Capacity Law. $dE = J.dM =$ transformation of energy.

This analysis of phenomena shows that variations of energy in their transformations are known only as the product of two terms. Of energy itself, the primal quantity, we know nothing as yet. Whether it ever can be known to man remains to be seen. Of the two factors which measure the change in energy, the first is called the intensity and the second the capacity. Examples of intensity are the absolute temperature, velocity of motion, the potential function, the double kinetic energy, force, surface tension, pressure, height, the Newtonian potential function, chemical intensity, electric and magnetic tension, electric and magnetic currents. These quantities are the gauges of the condition of the substance through which the work of the transformation of the energy is performed. Thus the temperature or pressure of a body prescribes the amount of the work required to produce a given rise in its heat or volume respectively. Now, the prerequisite that there shall be any transfer of energy whatsoever is that there must be differences of intensity in contact with each other. For any transfer of heat there must be two bodies in contact having different temperatures, as hot and cold pieces of metal; or two bags of air with different pressures, which are spherical before contact, but become deformed on touching each other, the bag of lower pressure yielding more than the one at higher pressure. Next, the transfer of energy is always from the substance of higher intensity to the one of lower intensity, as from the hot to the cold body, from the high pressure to the low pressure body. The second law of thermodynamics therefore becomes general by saying that every energy form endeavors to go over from a higher to a lower intensity. This is the intensity law and is universally applicable, so far as now known.

The second factor in energy changes is called the capacity, and examples of it are entropy, force, molar mass, the cyclic moment, distance, surface, volume, weight, resistance, chemical mass, electricity, magnetism, electric and magnetic density. The capacity measures the amount of the energy transferred from one body to another. If intensity measures

the amount of the disturbance of equilibrium, and conditions the rate at which the transfer of energy takes place, the capacity measures the amount of energy that is transferred when the form of energy is changed. Hence under the law of conservation the amount of energy that one body loses the other gains, and therefore the sum of the capacities taken throughout the process is constant. The amount of heat one body loses the other gains in the new equilibrium; the amount of pressure one body loses the other gains, in order that equilibrium may be restored. If this equilibrium is disturbed by some change in the intensity, then the capacity measures the amount of the energy that can transfer under these circumstances, and the total energy transformed is the product of the intensity and the variation of the capacity.

It may seem strange that the terms that we employ freely—force, mass, surface, volume, weight, electricity, and magnetism—are only forms of this capacity function, and that they are apprehended only during the instantaneous transfers of energy. It may cause surprise to perceive that the other set of terms we commonly talk about as entities, namely, temperature, velocity, potential and kinetic energy, height, pressure, tension, current, are perceived only during the transfer of energy; and it may be difficult to realize that we know nothing of heat, kinetic and potential energy, work, gravitation, friction, chemical, electric, and magnetic energy in their entities, but only in their processes of transfer. Energy is the great unknown entity and its existence is recognized only during its state of change. It may be surmised that we are here on the borderland of profound metaphysical speculations which we have no opportunity to enter upon at this time.

For our immediate subject in hand, namely, the illustration of the third canon of criticism, that every valid and new fact or law must be assigned to its proper rank in the hierarchy of science, we see at once that the foregoing analysis is of special significance. Here are more than a dozen examples from the processes of nature which can be classified under

one comprehensive general law, whose principle once fully comprehended makes it possible to critically analyze a multitude of subordinate statements regarding the details of thought and theory which are found in current scientific literature.

The above law has been stated as an equality $dE = J.dM$, but this is applicable only to the cyclically reversible phenomena. Now there is the second great class of phenomena, called the irreversible, which are not cyclic; that is to say, if a certain state exists in a body at an initial moment, and if after going through transformations it can be brought back to the same state again, it is reversible; but if it cannot return to that state, it is irreversible. Now there are many forms of energy-transfer which are irreversible; that is where the energy is wasted, so far as the efficient value of it is concerned, as where heat is lost by dissipation, electric and magnetic energy by radiation. Hence there is the law of dissipation of energy as well as the law of conservation, and the dissipation of higher power energy seems to be the dominant practical fact in the world around us.

Let us glance backward once more to a previous statement regarding the onward march of mechanics as the means of solving the physical problems of the universe. At first, under the influence of astronomy and mechanics of large masses, there was every prospect of its success; but when these principles were applied to molecular or atomic masses, and to physical laws of greater complexity, the difficulties of the mathematicians and physicists began, and they have continued to be insuperable to this day. The essence of the mechanical theory is *d'Alembert's* law of work, that force operating through a distance is the measure of such work, $dA = X.ds$. *Lagrange's* equation of work is derived by essentially ignoring spacial coördinates and substituting the parameters (intensities) which determine the condition of a substance while coupling it with the other quantity (capacity) which denotes the direction of the change. In doing this two steps are involved: (1) the potential energy of the me-

chanical system is ignored or thrown out of consideration, and the kinetic potential is alone employed; (2) the change in kinetic energy is assumed to be equal to the change in the energy of the system. In a word, all energy is kinetic, and no energy is potential—that is, after all the grand change from the mechanical system to the energy system of treatment. *Lagrange* made it possible by his equation; *Maxwell* first recognized the importance and necessity of this reformation, and out of it came his splendid electric and magnetic equations; *Helmholtz* adopted the same plan and found the laws of the cyclic and reciprocal system; *Hertz,* in his great treatise on modern mechanics, excludes the potential energy from his system; *J. J. Thomson* has successfully applied this method to a great number of physical problems, and he says, "We may look upon the potential energy of any system as kinetic energy arising from the motion of systems connected with the original system, and from this point of view all energy is kinetic, and all terms in the Lagrangian function express kinetic energy, the only thing doubtful being whether the kinetic energy is due to the motion of ignored or positional coördinates" (Dynamical Methods, p. 14). *Poincare* states, "I have demonstrated that the principles of thermodynamics are incompatible with mechanical principles of direct action and action at a distance; also mechanism is incompatible with the theorem of Clausius." *Helm* makes a long argument in favor of the view that energy transformations cannot be explained by mechanical analysis of the most advanced type. All this applies to the type of reversible or cyclic processes; but in the case of the irreversible or acyclic phenomena, even this law of *Clausius* is not available, for *Poincare* states (Thermodynamique, p. 422), "it results from this that irreversible phenomena and the theorem of *Clausius* are not explicable by means of *Lagrange's* equations." In a word, the first law of thermodynamics may have some mechanical analogues, but in connection with the second law there are no such analogues from mechanics. *Heaviside* has made a very stout effort to secure such analogues for

electric and magnetic relations, but each type has ended in some irreconcilable difficulty, and therefore no such analogues are known. The attempts of *Lodge*, *Boltzmann*, and others to illustrate the electric and magnetic phenomena by means of mechanical pictures must always be considered under the reservation that they can be only partially true.

I have thus attempted to give some idea of the battle royal between mechanics and energetics that is now going on, and have indicated that the banners of mechanics are certainly drooping, and that their standard-bearers are weary. Whether energetics is to be the final victor, or whether some stronger idea will be discovered, remains beyond the forecast of today. It looks now as if science were fast approaching those impenetrable mysteries which have confronted the metaphysician and the theologian for centuries; it seems certain that the attempt to construct this universe out of pure matter and the three simple laws of force is a failure; it may not be improper to assert that the available energy for doing useful work is being expended and that the world's supply is running down. There arises further questions: Where did energy spring from originally? What keeps up the supply, if it is now running down. What is to be the final state of things when the supply has gone? If the universe in its physical processes is really exhausting itself, what is this theory of evolution by which it is claimed that some combinations of energy, animal and human life, organic life, is coming up? Is inorganic life running down, and is organic life coming up? If this is so, what is the difference? In fact, what is life? Is mechanics destined to give place to energetics, and is energy finally to become tributary to the science of life whose first law has not yet been discovered? If not this, what is the true hierarchy in the existences, and does the pathway lead up from man and his little spark of life to some immense oversoul, and is that life the substance of the temporary phenomena we call this world?

OBITUARY NOTICES.

THOMAS ANTISELL.

1817–1893.

[Read before the Society, May 23, 1896.]

The ancestors of Dr. Antisell were French Huguenots, who fled from persecution to England, where part of the family remained and changed the name to "Entwisel." Another part settled in Kings county, Ireland, where the last male descendant died a few years ago.

Dr. Antisell was born in Dublin, Ireland, January 16, 1817, of Christopher and Margaret Antisell, formerly Margaret Daly. His father was a lawyer, who refused the "silk gown," or appointment as Queen's counsel, because he was not favorable to British rule in Ireland.

The Doctor was the second son in a family of three sons and two daughters, and commenced his medical education with Surgeon Daly, of Dublin, graduating from the Royal College of Surgeons, London. He studied chemistry with Sir Robert Kane, and for many years acted as his assistant. While residing in London he visited Paris and Berlin, and later settled in his native city, where he became a successful physician, also giving some lectures on agricultural chemistry. In 1848 he was obliged to leave his country on account of his connection with the young Ireland party, and chose New York city as the place of his political exile. Here he practiced medicine from 1848 to 1854, at the same time holding the position of lecturer on chemistry in a number of colleges, among them those at Woodstock, Vermont, at Pittsfield, Massachusetts, and at the Berkshire Medical Institute.

In 1854 his taste for travel led him to accept the position

of geologist with the Parke expedition in the railroad survey of southern California and Arizona, returning to Washington in 1856, where, on June 1, he was appointed first assistant examiner in the Patent Office. His work in the office related chiefly to chemistry, and he was promoted to be principal examiner on May 3, 1861.

On September 30 of the same year he resigned to enter the army as brigade surgeon of volunteers, with the rank of major. He served first with Banks' division and the Fifth army corps, then became successively medical director of the Department of the Shenandoah, Second corps, Army of Virginia, and Twelfth army corps; in October, 1862, was in Harewood hospital, Washington, D. C., and in 1863 president of a medical examining board, and post surgeon to August, 1865. He was brevetted lieutenant colonel, United States volunteers, March 13, and honorably mustered out of service October 7, 1865. In the service he was noted for his reckless disregard of personal danger for himself or his assistant surgeons when the wounded required attention in the rear of the line of battle, and probably saved the life of many a poor fellow by the prompt and skillful aid he rendered.

In 1866 he was appointed chief chemist in the Department of Agriculture, where in 1869 the writer first met him. The Japanese government was then trying to secure the services of competent foreigners to teach them modern civilization, and among their enterprises included an effort to improve the northern islands which form a part of their empire.

General Horace Capron, at that time Commissioner of Agriculture, was engaged for this purpose, and among the assistants he selected to go with him was Dr. Antisell, as technologist for the expedition. The party arrived in Japan in 1871, and the ability of Dr. Antisell in chemical work was so marked that he was soon transferred to the service of the Imperial government in Tokyo in connection with the making of inks for a new system of paper currency, dextrin for the post-office, and similar work. While in Japan he received a pressing invitation from General Stone, then in Egypt, to

take charge of a university at Cairo; but the climate of the East proved injurious to the health of his wife, who, with a daughter and infant son, had followed him to Japan, and he reluctantly returned to the United States in 1877. He was decorated by the Emperor of Japan with the Order of the Rising Sun of Meiji, thus making him a nobleman of Japan, with the right to carry two swords, and he always regarded his life in Japan with the utmost satisfaction.

On May 10, 1877, he was reappointed to the position in the Patent Office which he had resigned sixteen years before. He remained connected with that office until so much enfeebled by progressive paralysis that he could no longer perform his duties, and relinquished the service on September 30, 1891. He was tenderly cared for by his daughters, dying on June 14, 1893, in his seventy-seventh year, and was buried in Congressional Cemetery.

Dr. Antisell was twice married; first to Eliza Anne Nowlan, of Dublin, who died after his removal to New York city, and a second time to Marion Stewart Forsyth, of Detroit, Michigan, daughter of a paymaster in the United States Army. He had twelve children, of whom three died in infancy. Six daughters and two sons survived him; both the latter removed to Montana some time before his death.

In person Dr. Antisell was short and rather stout, with a florid complexion, especially in his younger days. In official life he had the reputation of being reserved and even somewhat brusque, but among his friends he was cordial and even warm-hearted, with an abundant supply of the wit and humor for which the Irish race have been always noted. The writer has abundant reason to remember many spontaneous acts of kindness from him in our occasional early intercourse, which were greatly augmented when the changes of official life brought us into closer relations.

During his whole career he was preëminently a teacher, especially of physiological chemistry, of which he had a thorough knowledge, as it was then understood. He was for thirty years connected with the Medical Department of

Georgetown University, from which he received the degree of Doctor of Philosophy. He was frequently in request as a lecturer before scientific bodies, and was connected with many scientific societies, such as the Royal College of Surgeons, England; the Royal Dublin Society, the Geological Society of Dublin, the Philosophical Society of Washington, and corresponding member of the Academy of Natural Sciences of Philadelphia, and the Geological Society of New York; also Fellow of the American Association for the Advancement of Science. He was one of the original founders of the Washington Chemical Society, being its first president, elected January 31, 1884; and he was the only honorary member ever elected of the Medical Association of the District of Columbia. Before leaving Ireland he published some small works, such as a "Manual of Agricultural Chemistry with its Application to the Soils of Ireland," Hodges & Smith, Grafton street, Dublin, 1845, and "Irish Geology," in 1846, and after his arrival at New York he wrote a "Home Encyclopedia of Arts and Manufactures," 12mo, 1855, and a book on the "Manufacture of Photogenic or Hydrocarbon Oils from Coal," etc., 8vo, New York, 1859. He also made numerous contributions to technical literature in the shape of essays in Government reports, and addresses before scientific and educational associations, especially the colleges with which he was connected.

WM. H. SEAMAN.

STEPHEN VINCENT BENÉT.

1827–1895.

[Read before the Society, May 23, 1896.]

Brigadier General Stephen Vincent Benét, United States Army, died January 22, 1895, at his home, 1717 I street northwest, in this city, aged just 68 years, having been born at Saint Augustine, Florida, January 22, 1827. He entered as

a cadet at the United States Military Academy in 1845, and served actively in the army from graduation, in 1849, to his retirement, in 1891, for about 42 years. He occupied an eminent position in his military career, and was identified with the important work of the Ordnance Department during this period, and attained distinction in a civil capacity as a writer and an authority on military law.

His ancestors on both sides were of Spanish origin, and were among the first settlers of Saint Augustine. His father was a highly respected citizen of that place, and for a long time surveyor of the port. Young Benét passed through four years at the Hallowell school at Alexandria, Virginia, and then entered the junior class of the University of Georgia at the age of sixteen. It was intended that he should, on graduating from the university, enter the profession of law, but before completing his course there he was offered and accepted an appointment to the Military Academy, where he maintained a high standing and graduated number three in his class. He was the first cadet from the State of Florida, which was admitted to the Union March 3, 1845. His intelligence, good habits, discipline of mind, and well-balanced physical and mental temperament were well developed during his student days, and served as elements of strength in his responsible and successful career through life.

On graduation he was assigned directly to the ordnance, as a brevet second lieutenant. His studious habits were preserved and his literary tastes made manifest, not only in the line of his chosen profession, but in that of his early predilection for the law. A translation from the French of Jornini's account of the campaign of Waterloo was made by him and published in 1853, and his treatise on "Electro-ballistic machines and the Schultz chronoscope" was published in 1873. When on duty at West Point, as assistant professor of geography, history, and ethics, he prepared his well-known treatise on military law and the practice of courts-martial, which was published in 1862 and afterward carried through several editions. This book was an authority on military law dur-

ing the period of the Civil War, and was for many years used as a text book at the Military Academy. In 1868 he served as assistant counsel in the Dyer court of inquiry, and acquitted himself with credit in the long and intricate proceedings accompanying that case. In 1855 the University of Georgia conferred upon him the degree of A. M., and in 1889 Georgetown University conferred that of LL. D.

As an ordnance officer, Benét was promoted in due course through the consecutive grades of lieutenant, captain, and major, and, skipping those of lieutenant colonel and colonel, received the marked distinction of being promoted at once to be Chief of Ordnance, with the rank of brigadier general. In the meantime he had served as assistant at Watervliet, Frankford, and St. Louis arsenals, and in the Bureau at Washington, and had two tours of duty at the Military Academy, first in the department of ethics and law, already mentioned, and afterward as instructor of ordnance and gunnery, at the head of that department. While serving in the latter capacity, 1861–1864, he was also employed as inspector of ordnance and projectiles and in experimenting at the West Point foundry with the Parrott rifled guns, which were extensively used during the war. In 1864 he was assigned to command the Frankford arsenal. He was thus during the period of the Civil War engaged upon most important duty connected with the proper manufacture and supply of war material, and for this reason his application to take an active part in the field operations was denied. By the act of Congress of March 13, 1865, he was made brevet major and brevet lieutenant colonel for faithful and meritorious service in the performance of these duties.

His services in command of Frankford arsenal were conspicuous for the successful introduction of the metallic cartridge for breech-loading small arms in the United States service, and the unexampled development of the machinery for making this ammunition, in which he was ably assisted by Master Armorer R. Bolton and Foreman Jabez H. Gill. The Springfield rifle of this period was caliber .50. The

center-fire cartridge was adopted for manufacture October 5, 1866, being chosen for its several apparent advantages over the rim-fire cartridge, which was then generally in use in arms made by private manufacturers. The proper development of breech-loading small arms had been chiefly retarded up to this period by the defects of the cartridge, but owing largely to what was then accomplished at Frankford arsenal in perfecting the cartridge, the successful and rapid development of breech-loading arms was assured.

Appointed Chief of Ordnance in 1874, General Benét administered the affairs of that department for the seventeen years following with much ability and clear foresight into the rapid and extensive changes in ordnance construction that marked this period. He took special interest in the dissemination of knowledge of current improvements to the whole army, and gave every encouragement to the officers of his own corps for study and investigation. Between 1873 and 1884 there was published from the Ordnance office a series of 357 ordnance notes, now comprising 12 volumes, which were distributed to the army, and in 1882 there was instituted a series of more technical papers, entitled "Notes on the Construction of Ordnance," which is still continued and has reached the seventy-first number.

General Benét always evinced a deep interest in the militia, and was instrumental in having the annual appropriation for it increased from $200,000 to $400,000. The splendid system of target practice in the army also owes much to his efforts. The .45-caliber Springfield rifle was introduced in the service about the date of his accession, but before his retirement the preliminary steps had been taken to introduce the present service .30-caliber magazine rifle. Probably the most important change of recent years in ordnance has been the substitution of steel for cast and wrought iron in the construction of guns, and in this General Benét was an advanced advocate. He clearly foresaw the benefit of the change, and directed the experiments necessary to lead up to it in a manner that made it an assured success, and, following this, under

many difficulties and embarrassments, succeeded in establishing the extensive factory for steel guns which is now in operation at Watervliet arsenal, West Troy, New York.

He was happily married in 1856 to Miss Laura Walker, of Kentucky, who survives him, with two sons, Captain J. Walker Benét, Ordnance Department, United States Army, and Lawrence V. Benét, Ordnance Engineer of the Hotchkiss Ordnance Company.

ROGERS BIRNIE.

THOMAS LINCOLN CASEY.

1831–1896.

[Read before the Society, May 23, 1896.]

One of the forty-three signers of the initiatory letter to Professor Joseph Henry, in the early months of the year 1871, looking to the establishment of the Philosophical Society of Washington and requesting him to preside at its first meeting for organization, was Major Thomas Lincoln Casey, of the Corps of Engineers, United States Army, then in charge of the Division of Fortifications in the office of the chief of that corps. He had been stationed in Washington somewhat more than three years and had become well known among the learned men of the city for his interest in and acquaintance with the sciences qualifying him to aid materially in the foundation of this Society.

He was born on May 10, 1831, at Madison Barracks, Sacketts Harbor, New York, where his father, the late Brevet Major General Silas Casey, a regular army officer and graduate of the West Point Military Academy, was then stationed. Naturally the child thus born and growing up in the army became a part of it, following the steps of his father and entering the Military Academy himself at the age of seventeen, on July 1, 1848. From this time onward to the day of his death his career was unusually successful and brilliant. It

is probably quite true to say that he failed in nothing that he undertook, great or small.

He was soon near the head of his class at West Point, then first captain of the Corps of Cadets, and finally at the very head of his class on graduation. Being then, July 1, 1852, promoted to brevet second lieutenant in the Corps of Engineers, he was assigned to duty on the construction of Fort Delaware and on river and harbor works for two years. During the next five years he was assistant instructor and then principal assistant professor of engineering at the Military Academy. From 1859 to 1861 he was in command of engineer troops in Washington Territory, one of the works there accomplished being the construction of a wagon road from Vancouver to Cowlitz river, through the difficulties presented by primitive forest and remoteness from civilization. This road was the first land communication between the Columbia river and Puget sound.

In the first year of the rebellion, 1861, he returned to the East and served as assistant engineer on the staff of the commanding general of the Department of Virginia. At this time he reached the rank of captain in his corps, when, although but thirty years of age, he was immediately ordered to take charge of the construction of the several heavy permanent fortifications on the coast of Maine, consisting of Forts Preble, Gorges, and Scammell, in Portland harbor; Fort Popham, at the mouth of the Kennebec river, and Fort Knox, at the narrows of the Penobscot river—operations requiring the maturest engineering and administrative ability. All these were masonry forts of the highest order in solid granite and brick-work. At that critical period, with the activity incident to extensive military operations in the field, great demand was made on the professional resources of the Corps of Engineers, and it was a high honor for a young captain to be entrusted with so responsible a duty. It was necessary that he should work out problems of management inevitably new to a young man, for those works were not only extensive individually, but numerous and widely sep-

arated along a coast at that time slow to traverse, where tidal foundations had to be considered, workmen trained and organized, water transportation provided, and the rigors of Maine winters encountered. But the celebrated General Totten, then for many years the chief of the corps, knew his man, and that he possessed the qualities of good sense, ingenuity, and perseverance, as well as sterling ability and integrity, warranting the trust reposed in him. These characteristics had been up to that time, and were ever afterward throughout his whole career, so evident that his superiors never seemed to feel hesitation in assigning him to any duty whatever.

For six years he carried forward the construction of these forts, bringing them within the first three years to a high condition of efficiency—excellent progress for works of that kind at that time.

On March 2, 1863, Captain Casey became a major in his corps, and in that year was sent on special duty with the North Atlantic squadron in the first expedition for the capture of Fort Fisher, North Carolina. Many other duties of an important nature were performed by him during those years.

On November 18, 1867, Major Casey came to Washington to enter upon the duty in which he was engaged when he took part in the founding of this Society.

At the first meeting of the Society, on March 13, 1871, he was elected a member of the General Committee, to which he was twice reëlected, serving continuously for three years. In the early years of the Society he was active in its affairs and a frequent attendant at its meetings, occasionally taking part in the discussions. In the later years increased duties and responsibilities and less robust health combined to withdraw him from further activity in the Society and keep him at home with his family during most of his leisure hours, although he continued his membership to the last.

On March 3, 1877, he was relieved from duty in the office of the Chief of Engineers and placed in charge of the con-

struction of the new building for the State, War, and Navy Departments, then about one-quarter built, the care and maintenance of the Washington aqueduct, and the Office of Public Buildings and Grounds in the city of Washington. The condition of affairs at that time called for a strong, fearless, tactful, active, judicious officer, qualifications that Colonel Casey was known to possess. In a very short time the business and operations that had become loose and uncertain were proceeding by simple, direct, and expeditious methods, doubts as to the outcome being dispelled and large sums of money saved in all directions. In this way the State, War, and Navy building was completed, as proposed a few years before, on March 1, 1888. Had the Washington Aqueduct remained in his charge, instead of being transferred to other hands when the extension of the conduit to the heights north of the city was undertaken, the misfortune of the so-called Lydecker tunnel would never have occurred.

Hardly had Colonel Casey mastered the main questions involved in the management of the construction of the great department building and the other affairs referred to when he was ordered to add to his duties that of engineer to the joint commission created by Congress for the completion of the Washington monument. For nearly a quarter of a century a short but heavy section, 156 feet in height, of a proposed obelisk of some 600 feet for this purpose, had stood awaiting the provision of means for its continuance and completion. Finally the Congress accepted the responsibility, and received the work from the hands of the society which had hitherto had control of it. Investigation proved that the foundation was entirely inadequate to carry the proposed shaft, and that the first requisite was to sufficiently strengthen it, if possible and practicable. No adequate plan for this had been proposed, and when Colonel Casey took charge, on June 25, 1878, he found himself face to face with an entirely new and most difficult engineering problem. The sentiment against removing the old masonry, and building entirely anew, with a new foundation, the great weight of the existing

masonry, and the known weakness of the foundation, all rendering operations on it exceedingly delicate, were most serious elements in the case. What sort of strengthening was needed and how to execute it safely were the questions. The problem was at once attacked with characteristic vigor and energy by Colonel Casey. Night and day for a few weeks the subject was studied and plans of operations devised, and in the amazingly short space of one month from the day he took charge an original project was prepared and submitted to the joint commission, which immediately approved it. The work was undertaken as soon as materials and machinery could be procured, and the extremely delicate operation of underpinning and buttressing with concrete a foundation carrying some 35,000 tons on an earth bed yielding under its enormous load at every touch was successfully accomplished in less than a year and a half. The structure naturally moved somewhat during the operations, leaning slightly one way and another as the inevitable slight settlements took place, but the algebraic sum of these movements was zero, and the total settlement of the center of gravity only about $2\frac{1}{4}$ inches. The performance of this work properly gained for its engineer a world-wide reputation, particularly in the profession of civil engineering, but the special problems of the completion of the whole monument had not all been solved in the foundation. The construction of the shaft proper was a comparatively simple matter, but its walls were necessarily made as thin as possible to reduce to a minimum the load on the foundation, and this led to the unique problem of placing, without the use of metal, a stone apex or pyramidion, 55 feet in height, on the 18-inch edge of the four walls of the square shaft, whose sides were 34 feet $5\frac{1}{2}$ inches in length, at 500 feet above the ground. This square was entirely hollow, without cross-ties of any kind. The design and execution of this portion of the monument was also expeditiously accomplished, and on December 6, 1884, Colonel Casey himself set the capstone, amid the cheers of the people and the salute of cannon, and the monument was successfully finished, six years after

he took charge of it. The graceful proportions of the shaft largely resulted from the taper fixed by the original builders, but those of the pyramidion were the result of his own investigation, bringing the noble pile to that acme of delicate, beautiful simplicity which, combined with the whiteness of its material, reflecting the ever-changing atmosphere and cloud colors, makes it an object of unceasing admiration by all beholders. Such a desirable outcome was not anticipated by the public, which hardly knew what the real proportions of the monument were to be, until the apex was set and the structure finally laid bare to be viewed as a whole.

The manner in which Colonel Casey carried through this particular work is the best illustration of his qualities as a man. No man of less tenacity of purpose, force of character, energy, and industry could have accomplished it in so short a time. Nothing that he ever undertook was allowed to lag for a moment. He was uneasy and under strain constantly until the point under consideration was settled or the work in hand finished.

He became a colonel in the Corps of Engineers in 1884 and in 1886 president of the Board of Engineers for Fortifications in New York city, where he remained until 1888, when he was appointed brigadier general and chief of his corps, and returned to spend the remainder of his days in Washington. At this time Congress was in a dilemma regarding the construction of the new building for its library on Capitol Hill. The work having been begun was proceeding unsatisfactorily. Uncertainties as to its ultimate cost, design, and time of construction had so impressed Congress that it was quite on the verge of suspending the operations indefinitely when the return of General Casey to Washington determined them to place the whole charge independently upon his shoulders, one of the highest compliments ever paid by Congress to the sound sense, judgment, and real usefulness of an individual. The law was promptly passed, and on October 2, 1888, he took charge of the work. The office was at once reorganized on the simplest business lines, and

from that day the work, beginning with the foundations, moved in a quiet and uninterrupted progression until nearly completed at the time of his death. Without premonition he was taken suddenly ill on his way to the Library building on March 25, 1896, and in a few hours passed away.

Throughout his whole professional life he was constantly in busy harness, generally charged with heavy and responsible works and duties far more numerous and absorbing than even those here specially mentioned would indicate. As a member of his corps in the army, he was ever intensely loyal to its best interests and jealous of its good name as a servant of the Government.

In conversation and business he was direct, thorough, and painstaking, considering in advance every step in detail.

His nature was unusually sensitive, causing him often to be blunt in manner, especially to strangers, and to have a keen eye for men with selfish motives; but he was always frank and outspoken, and those who knew him well realized his solid honesty and kindness of heart. He possessed a remarkably social and genial disposition and a lively sense of humor, and his friendships, though not numerous, were of the sweetest and heartiest kind.

He wrote little and rarely appeared in public, but almost constantly confined himself to the Government duties in which his life was bound up.

General Casey was a member of the National Academy of Sciences, an officer of the Legion of Honor of France, member of the Society of the Cincinnati, Loyal Legion, Century Association of New York, and New England Historical and Genealogical Society.

In early life he married Emma Weir, daughter of Prof. Robert W. Weir, of the Military Academy, who, with two sons, Captain Thomas L. Casey, of the Corps of Engineers of the Army, and Edward P. Casey, an architect in New York city, survives him.

Bernard R. Green.

DANIEL CURRIER CHAPMAN.

1826–1895.

[Read before the Society, October 24, 1896.]

In complying with the request to present a memorial address of our late associate, Daniel Currier Chapman, a duty I can hardly hope to perform with justice to the man, a high appreciation is felt of the privilege of preparing for the archives of the Society the record of his successful labors.

Mr. Chapman was born at South Corinth, Vermont, October 27, 1826, and died in Washington, January 3, 1895. He was the son of a farmer and miller, said to have been one of the progressive men of his district, and gifted with a mechanical skill that enabled him to make his own improved implements of labor. The son inherited the skill in mechanics that later in his life did him good service and helped him to render the valuable assistance uniformly accredited to him by his employers.

As a boy and youth he labored on a farm in summer to earn the money for his winter schooling, until his graduation from Bradford Academy. After teaching school several winters he went to Manchester, New Hampshire, and learned the trade of machinist. In 1852, at the age of twenty-six, he moved to New York, and seems to have established himself as a machinist, with a more ample range for his inventive skill. At this time, it is said, he produced the first buttonhole machine ever made; he was also engaged in manufacturing the separate parts of sewing machines, then in their earlier stage of development.

In 1863 Mr. Chapman purchased a small gallery in the upper part of the Bowery, in New York, and laid the foundation for the reputation he subsequently earned as an expert, or, more properly, a *scientific*, photographer. His skill as a mechanic was, doubtless, of great help to him in these

early days of photography, as it was subsequently, when called upon, in the application of the art to the more precise measurements of scientific work. The late Prof. Louis W. Rutherfurd, doubtless attracted by the reputation Chapman had acquired, combining the qualities of mechanician and photographer, had employed him at intervals for a number of years, and secured his services for the observatory in 1868. When we recall the nature of the investigations Professor Rutherfurd was then engaged upon, we can realize the wisdom of his selection. Mr. Chapman continued at the Rutherfurd Observatory until 1879, when he accepted an offer from Dr. Henry Draper; and in February, 1882, he received an appointment, under the Superintendent of the Coast and Geodetic Survey, in the United States Bureau of Weights and Measures. During these fourteen years Mr. Chapman won the friendship of many men of science, and is remembered by them for his valuable services to Professor Rutherfurd. It was during this period, also, that he gained his greatest reputation as a photographer, his development of some of Professor Rutherfurd's negatives proving almost marvelous in their effects. In 1870 he accompanied one of the United States parties, as photographer, to observe the eclipse of the sun. While employed in the Bureau of Weights and Measures his skillful work was highly appreciated, and was probably most fully exemplified, in ruling gratings with a little machine of his own construction worked by electric power.

In February, 1886, on my solicitation, Mr. Chapman was transferred to the position of electrotyper and photographer in the engraving division of the Coast and Geodetic Survey Office. This division was at that time my personal charge, and continued under my direction until shortly after his death. The last nine years of his work were, therefore, under my supervision. In this time I learned more fully to appreciate the man, his sterling integrity, unity of purpose, and unflagging energy in solving the problems that beset us. I found him a man with a large fund of information, but so unostentatious that it was only in the heat of discussion I

could sound the depths of his knowledge. Association with him was a pleasure I can only look back upon, but the lessons taught me in his experience are treasures to be ever remembered.

In electrotyping, Mr. Chapman essayed a new rôle, but his studies in electricity and practical experience with its application in other branches equipped him, with very brief instructions, to undertake the work and carry it on most successfully. I need not enter upon the difficulties he overcame, nor the experiments he conducted while obtaining a mastery of the subject, interesting and creditable as they were; let it suffice that in the end he secured an average increase in deposit of reguline copper of over 30 per cent. with the same consumption of fuel—in this case the zinc battery plates—and at times almost reached the maximum deposit to be obtained with a perfect plant. As photographer he had only to adapt his knowledge to a new class of work, but, learning the requisite conditions, he was not satisfied until he had filled them and could furnish photographic prints for the engraver's use on the exact scale proposed for the engraving. His marked ability as a mechanic helped him in this, as in other work, having devised and constructed a machine for adjusting to true scale prints of negatives from a distorted drawing; but his reputation as a photographer was made long before his entry upon the Survey—a reputation that has been cordially expressed in a recent number of the *Photographic Times*, and to which I am indebted for some of the facts of his life referred to in this paper.

Mr. Chapman was elected a member of the Philosophical Society December 22, 1888. He was a constant attendant at the meetings, contributed to the discussions, and evinced a laudable interest in the welfare of the Society. He was a life member of the Polytechnic Club of the American Institute of New York City and a member of the National Geographic Society.

If our success in life is measured by the warmth of the friendships we leave behind us, or by the record of the work

we have accomplished in our careers, Mr. Chapman was a successful man. But these are the product of honor and intelligence, the embodiment of the Christian spirit, whatever may be our professed belief. Under the guardianship of an upright life, Mr. Chapman held the doctrines of pronounced spiritualism, and surely we can wish for him now no happier fate than the realization of the belief of his manhood.

HERBERT G. OGDEN.

GEORGE EDWARD CURTIS.

1861–1895.

[Read before the Society, May 29, 1897.]

George Edward Curtis was born July 8, 1861, at Derby, Connecticut, and died February 3, 1895, at Washington, D. C.

His father, George S. Curtis, and his mother, whose maiden name was Catherine Lewis Curtis, were descendants of the Curtises who settled at Stratford, Connecticut.

He lost his father when but fifteen months old. An only child, he was much with his mother, and early developed a love for books and an ambition to get a college education. His youth was spent in his native town, where he attended the public schools and fitted for Yale College, entering that institution in 1878.

His life was so regular and methodical that it contained few incidents of unusual importance. He was of small stature and always bore himself erect. His sense of justice and equity was acute, and he possessed a consideration for the feelings of others which brought him to their defense. The principal of a school Curtis once attended placed in the school a copy of *Harper's Weekly.* At that time the paper was, to say the least, radically anti-Catholic. Young Curtis, desirous of defending such of his schoolmates as might take exception to the paper, wrote a very able criticism concerning the matter. Although only a schoolboy's composition, in

finish and argument it would have done credit to one of much maturer years.

He had a keen appreciation of humor in others, but possessed little in his own constitution. Not precocious, though gifted, he was conscious that success demanded the best use of all his energies. His school friends say he never had time for anything but work.

Early in life he became a Christian and member of the Methodist Episcopal Church. During his residence in Washington he was a member of the Congregational Church. His bright and sunny disposition brought him many friends.

In college he was very enthusiastic in his work and took the first prize in mathematics in his sophomore year, as well as the first mathematical prize in his senior year and the prize for solution of astronomical problems. A good student in all subjects, he excelled in mathematics, and graduated with honor in 1882, twelfth in a class of 119. In 1887 he was granted the degree of A. M. in recognition of his advanced work.

About the year 1880 the National Weather Service, then known as the Signal Corps of the Army, was reorganized by General Hazen, thus opening up a new and attractive field of activity for young college men with a taste for meteorology. In March of 1883 Mr. Curtis enlisted in the service and entered upon his new career with enthusiasm. He came well equipped for the physical problems to be dealt with. He was at once assigned to duty in Washington with Mr. C. A. Schott, of the United States Coast Survey, who was engaged upon the reduction of the magnetic observations of the international polar stations at Lady Franklin bay and Point Barrow. After the completion of this work Mr. Curtis was for several years associated with Professor Abbe in the general scientific work of the Weather Bureau. His work during this period called forth high praise from Professor Abbe, who recognized in Mr. Curtis a man of excellent abilities and one well equipped to do original scientific work.

In 1884 Mr. Curtis published his first contribution to

science, "The Effect of Wind Currents on Rainfall," which appeared as one of the series of Signal Service Notes of the Weather Bureau. Mr. Curtis rendered valuable assistance in the preparation of certain sections of Professor Abbe's "Treatise on Meteorological Apparatus and Methods," which formed part 2 of the Annual Report of the Chief Signal Officer for 1887. Probably the best work which he did while connected with the Weather Bureau is contained in this treatise and in papers embodying studies made in connection with the preparation of this report.

In September of 1887 Mr. Curtis was assigned to duty at Topeka in connection with the work of the Kansas State Weather Service; he remained there only a few weeks, however, before severing his connection with the Weather Bureau to become associated with Washburn College, in Topeka, as assistant professor of mathematics. This position he held until December of 1890, when he received an appointment in the United States Geological Survey. Under the direction of Captain Dutton he took up the meteorological problems connected with the irrigation survey of the Western States and Territories. His duties in the survey enabled him to live an outdoor life in the high and dry plateau regions of the West—a matter of vital importance to him, as symptoms of tuberculosis were already apparent. Mr. Curtis remained in the West until June, 1890, and then returned to Washington to work up the results of his observations. In August the work of the irrigation survey came to an end, and Mr. Curtis accepted a position in the Smithsonian Institution. Here he was chiefly engaged upon the revision of the Smithsonian meteorological tables. He also assisted Professor Langley in the preparation of his memoir on "Experiments in Aerodynamics," in the preface of which the author refers to Mr. Curtis as giving most efficient aid in the final computations and reductions.

In the summer of 1890 Congress authorized the expenditure of a large sum of money for carrying on experiments in the artificial production of rain. These experiments were

carried on mostly in Texas, under the direction of a special agent appointed by the Secretary of Agriculture. Mr. Curtis was appointed meteorologist to accompany the expedition and report directly to the Secretary of Agriculture. His report, which attracted attention at the time, was unfavorable to the claims of the leader of the expedition and did not find place in the official report of the experiments, but was privately printed in several scientific journals.

While connected with the Smithsonian Institution Mr. Curtis prepared the definitions of the meteorological words from M to Z of the Century Dictionary. He was also associated with Professor Abbe in the establishment of a course of instruction in meteorology in the Columbian University.

After three years' residence in Washington Mr. Curtis found it necessary, on account of dangerous symptoms, to return to the dryer regions of the West. He reëntered the United States Weather Bureau and was assigned to duty at Tucson, Arizona, in December of 1893. Here he remained only six months. Not getting the relief he hoped for, he wandered from place to place in Arizona and Colorado in the vain hope of improving his health. In January of 1895, despairing of recovery, he returned to Washington to spend his last days among his many friends.

While devoting his best energies to the study of meteorology, Mr. Curtis always maintained a lively interest in other fields of inquiry and in the absorbing events of the day. He delighted in controversy. Aggressive in manner, he was always a conspicuous figure in a discussion. His strong aversion to the military organization of the Weather Bureau, combined with a spirit of independence, brought him into frequent collision with higher officials. This disposition doubtless stood in the way of a more rapid advancement in the service which his abilities merited.

J. S. Diller and O. L. Fassig.

ROBERT EDWARD EARLL.

1853–1896.

[Read before the Society, May 23, 1896.]

Robert Edward Earll died at Chevy Chase, near Washington, March 19, 1896. He was a native of Illinois, whither his parents had gone as pioneers in 1835, settling in the northeastern part of the State, near Lake Michigan.

His father, Robert C. Earll, a native of the State of New York, belonged to the well-known Earle family of New England, the peculiar spelling of the name with the double terminal "l" having been adopted by himself. His mother, Sarah Montgomery, was of Virginian parentage.

Mr. Earll was born at Waukegan, August 24, 1853, and was prepared for college in the public schools of his native town. In 1873 he entered the old University of Chicago, where he remained one year, then was transferred to the Northwestern University at Evanston, where he was graduated in 1877 with the degree of Bachelor of Science, subsequently obtaining, in due course, that of Master of Science.

He had a fondness for natural history, and through the influence of Mr. James W. Milner, a fellow-townsman and a graduate of the same university, who was at that time deputy United States Commissioner of Fisheries, he secured a position upon the United States Fish Commission, and was appointed to the position of fishculturist by Professor Baird in 1877. In 1878 he was transferred to the scientific staff of the Commission, and engaged in the same summer upon work at the Gloucester station.

From 1879 to 1882 he was employed as special expert in the Fisheries division of the Tenth Census, and collected the statistics of the sea fisheries of northern New England and of the Middle and Southern States.

In 1883 he was appointed a member of the staff of the United States Commissioner to the International Fisheries

Exhibition in London, and rendered efficient service as executive officer and deputy of the Commission. His remarkable aptitude for exposition work was first demonstrated on that occasion.

Shortly after his return from London, in 1883, he was appointed chief of the Division of Fisheries in the Fish Commission, and also an honorary curator in the National Museum. In 1888 he resigned his place in the Commission and became a regular member of the Museum staff. In this capacity he served for the remainder of his life, much of his time being occupied in work for the several expositions in which the Smithsonian Institution has participated. He was chief executive officer for the Institution at Louisville in 1884, at New Orleans in 1885, at Cincinnati in 1888, at Chicago in 1893, and at Atlanta in 1895, and for three years past has also acted as editor of the *Proceedings* and *Bulletins* of the National Museum.

He was a man of great force of character, and recognized as one of the most efficient of exposition administrators. His unselfish devotion to his work and his absolute trustworthiness were appreciated by all who knew him.

He published a considerable number of important papers upon the habits of fishes and the methods of the fisheries. He made extensive collections upon the Atlantic coast and the Great Lakes, and discovered many species of fishes and invertebrates new to science. He was one of the best authorities upon the natural history of our anadromous fishes.

He was also a skillful and ingenious fishculturist, and rendered excellent service in the early experimental work in the propagation of the shad and in the establishment of the cod-hatching station at Gloucester, Massachusetts.

He was a man of the purest personal character and deeply interested in philanthropic work, and the time which was his own was devoted chiefly to efforts for the moral and material good of others. His reputation as a naturalist would undoubtedly have been more widely established had he confined his efforts entirely to research. He chose, however, to give

his attention chiefly to administrative work, and his efficiency in this was of the highest character.

He was a man who, more than almost any whom I have known, corresponded to Emerson's ideal of independence. He did what concerned him, not what others thought he ought to do. In the midst of the crowd "he kept with perfect sweetness the independence of solitude."

G. BROWN GOODE.

WILLIAM WHITNEY GODDING.

1831–1899.

[Read before the Society January 6, 1900.]

William Whitney Godding, the subject of this memoir, was of English descent, but his ancestors had resided in Massachusetts for three or four generations. He was born in the town of Winchendon, in Massachusetts, May 5, 1831. His native place is a typical New England town—clean, bright, well lighted, well paved, and with the never-failing public library, lyceum, and school-house. It is a picturesque place. A busy manufacturing town forms a part of it, and beyond is the "middle town," as it is called, full of comfortable residences. A friend who accompanied Dr. Godding's remains to their place of interment in Winchendon describes the residence in which he was born as an old-fashioned house, with curious gables and broad piazzas, embowered in maples and fruit trees, and with a fragrant flower garden in front. In the distance the towering peak of Monadnock, in New Hampshire, was clearly visible.

In the life of a man who has attained to high distinction it is always interesting to be made aware of the surroundings which influenced his boyhood days.

Our friend's father was Dr. Alvah Godding, a well-educated, well-cultured physician, whose skill, kindness, and benevolence are remembered to this day. He was emphat-

ically the "poor man's doctor," for his unpaid service was given without stint to the poorest and humblest of his neighbors. This tender generosity of mind was amply inherited by his distinguished son.

Dr. Godding's mother was Mary Whitney, of an English family of that name which settled in Waterford, Massachusetts, in 1635. She was a woman of remarkable character, strong in her beliefs, an admirable mistress of her household, devoted to her good husband and her children, and so forceful that a minister once said of her, that "half a dozen men with her firm convictions and moral courage would revolutionize a town."

It was under the training and example of such parents that young Godding grew up as a boy. He was educated at the district school, and later at a private academy. In his sixteenth year he was sent to Brown University, at Providence, Rhode Island. He had not been there many months before he was convinced that he needed a more thorough education to prepare him for a collegiate course. He went therefore to an academy in Andover, Massachusetts, where he passed two years in diligent study. In the year 1850 he entered the freshman class at Dartmouth College, where he graduated as Master of Arts in 1854, being then 23 years of age. After graduating he began the study of medicine in his father's office. Later he was sent to New York, and passed a year in the College of Physicians and Surgeons. Twelve months after his return he received the degree of Doctor of Medicine from the Medical College of Castleton, Vermont. Being now fully equipped for his professional career, he was associated with his father in the practice of medicine at Winchendon, but eighteen months later, in June, 1859, he accepted the position of assistant physician in the State Hospital for the Insane at Concord, New Hampshire. It was in this way that he entered upon the study and care of the insane, which was to be his life's work and source of distinction. Marrying in 1860, he took his wife to the Concord Hospital and remained there two years longer, when

he resigned his position and entered upon the practice of medicine in Fitchburg, Massachusetts. This was the only break in his long career as a psychiatrist. At the end of a year he was offered by the late Dr. Charles H. Nichols, then superintendent of St. Elizabeth, the Government Hospital for the Insane, the position of second assistant physician in that institution. He came to Washington in September, 1863, and in the following seven years he established a high reputation for indefatigable industry and for skillful and tender care of the hapless beings under his charge. So well had he become known that in 1870 he was appointed superintendent of the State Hospital for the Insane at Taunton, Massachusetts. He remained there seven years, and Dr. Crayke Simpson, who has written a most loving and graceful tribute to his deceased friend, and to whose memoir I am indebted for much of the foregoing details, says that Dr. Godding always looked back upon that period as the happiest years of his life. He was in his native State, for which he entertained a most loyal affection, and he felt the satisfaction which an able man experiences in the consciousness of thorough discharge of his duties. In 1877 Dr. Nichols resigned his position as superintendent of St. Elizabeth in order to accept the superintendency of the Bloomingdale Asylum in New York city. He recommended to the Board of Visitors and the Secretary of the Interior the appointment of Dr. Godding as his successor.

Dr. Godding assumed the office in September, 1877, and remained in it until his death. The work which he achieved in those twenty-two years can only be briefly alluded to in this sketch, but it may be justly characterized as immense. His high character, his earnestness, and his genial manner soon acquired for him the confidence of men in official station. As a result, he succeeded in obtaining liberal appropriations of money from the Congress, with which substantial buildings were erected, and the grounds were laid out in a tasteful manner for the comfort and enjoyment of the patients. It is to be remembered that not only the insane from the Dis-

trict of Columbia, but insane patients from the army and navy, and from the numerous homes for disabled volunteer soldiers are received at St. Elizabeth.

During the past year insane soldiers have been brought thither from Manila even to find a kindly refuge until reason may be restored or death bring a happy escape. It may seem strange that soldiers, young and active men, should furnish such a contingent to the hospitals for the insane. It is to be remembered that this occurs chiefly among volunteers, men who without the preliminary training of the soldier have left the farm and the village to take part in the tragic scenes of war. During the war of the rebellion many a man was found in a ragged uniform wandering aimlessly through the country, his "descriptive list" gone, and no means of identification possible. Such unfortunates were sent to the nearest State asylum, where the Government humanely provided for them, and many hundreds lived and died in these places, unknowing and unknown. In some instances, when reason was recovered, friends were sent for and carried away a relative literally "called back to life." There is something very pathetic and not generally thought of in the fate of these victims of war's "fierce alarms."

In the last report of the Government hospital, under Dr. Godding's care there were nearly 2,000 patients under treatment. Think of the incessant watchfulness and vigilant care needed to provide the feeding, clothing, nursing and treatment of such an army of the diseased in mind, many of whom are turbulent and hopelessly mad. The superintendent has the assistance of five zealous and able assistants, besides a "night physician," whose title indicates his duty; but Dr. Godding was the ruler, and to him all repaired for counsel and aid. He never failed to meet them—officers, nurses, attendants, and patients—with kind words of encouragement, ready advice, and the exercise of authority to remedy their difficulties.

It has been often felt to be a matter of grave regret that the engrossing household cares, to use a familiar phrase,

should fall to the lot of the superintendent of a hospital for the insane. It would seem better that such a man should be able to devote himself exclusively to the care of his patients, to the study of the varying phases of insanity, and to the perusal of the writings of his confrères in such pursuits. Instead of these lofty occupations, he is in fact obliged to serve, in military phrase, as quartermaster and commissary for a small army of patients, attendants, and skilled and unskilled laborers. He must understand the running of the powerful engines required to supply the water and to keep the great fans moving which pump fresh air into the hospital. If new buildings are to be erected and old buildings repaired and altered, the superintendent must oversee the work as it is done. It can be imagined that with such constantly recurring claims for his attention there can be but little time available for his intellectual work. The attempt to separate these purely administrative duties from those of the physician in charge has been tried, but, it must be admitted, with no satisfying result. The functions of the administrative official have been found to clash with those of the scientific superintendent. The latter is undoubtedly the best, indeed the only, judge as to what is needed for his patients. In spite of theory, therefore, our great hospitals for the insane are still managed on the old plan. It is true that in most cases the man who has reached the high position of superintendent is one whose force of character and long experience has fitted him for his arduous task. Dr. Godding was one of these, and notwithstanding the heavy drafts upon his time from his administrative duties, he found leisure for professional studies and for the lighter elegancies of English literature, of which he was a diligent student. He had a warm love of poetry, and indeed had a happy faculty of composing graceful verses. Of the many societies which elected Dr. Godding to membership, I think perhaps he enjoyed the meetings of the Literary Society of Washington more than any others. It was a relief and a happiness to throw off the cares of his great office and listen to essays on pure literature. He took a ready part in

the ensuing discussions, and occasionally gave us a paper of his own. He was at one time president of the society.

Dr. Godding was a member of the Philosophical Society during twenty years, but I cannot find that he ever read anything before us. His own studies were exclusively professional, and he had that recommendable quality of never speaking of what he did not thoroughly understand. Though firm and courageous in the discharge of his official duties, Dr. Godding was essentially a modest, unobtrusive gentleman. His published writings were numerous, but all related to his especial line of work. He was a member of many distinguished scientific and medical societies, a list of which forms an appendix to this memoir.

In his family relations Dr. Godding was to be seen at his best. Adored by his wife and children, he repaid their devotion with all the tenderness and love of his great heart. His widow, with two daughters and a son, survive him. In the spring of 1899 his health began to fail, undermined by his many years of arduous and unselfish labors, and he died on the 6th of May, 1899.

Some time ago, at a meeting of the Literary Society, I happened to quote to him a stanza from a poem the title of which was "Evening thoughts on death." The author was Sir John Bowring, well known as a scholar and linguist, but whose poems and translations are less remembered than they deserve to be. The good doctor's eyes moistened at the recital, for he had a keen sensibility to the tender and pathetic in poetry. He was younger than I, and I little thought that I should furnish a modest tribute to his memory by quoting the same stanza. When I think of this good man at rest in the peaceful cemetery in his native town, his life-work well done, his father and four generations of his forbears lying around him, and the beautiful New England scenery which he loved so well hallowing his grave, I think the lines in question singularly appropriate. This is the stanza: *

* Bowring (John): Matins and vespers, 1823.

No sorrows now disturb him,
No disappointment there;
No worldly pride to curb him
In his sublime career.
Heaven's azure arch is over him,
Earth's tranquil breast beneath.
The stars are brightly glowing,
The breezes play around,
The flowers are sweetly blowing,
The dew is on the ground,
And emerald mosses cover him,
How beautiful is death!

ROBERT FLETCHER, M. D.

The following list comprises the societies to which Dr. Godding belonged:

Medical Association, District of Columbia; Medical Society, District of Columbia; Massachusetts State Medical Society, American Medical Association, American Medico-Psychological Association, British Psychological Society, Medico-Legal Society, Columbia Historical Society (charter member), Literary Society of Washington, Colonization Society, American Social Science Association.

GEORGE BROWN GOODE.

1851–1896.

[Read before the Society, December 9, 1899.]

George Brown Goode was born in New Albany, Indiana, February 13, 1851, and died in the city of Washington September 6, 1896. He traced his ancestry in this country to John Goode, of Whitby, who settled in Virginia prior to 1661. He was educated at Wesleyan University, Middletown, Connecticut, being graduated in 1870, and early showed a decided taste for natural history, taking a post-graduate course under Agassiz at Harvard, whence he returned in 1871 to Middletown to assume charge of the small University museum. He became associated with the National Museum and engaged in the work of the Fish Commission under Professor Baird in 1873 and soon was a leading spirit in the

Smithsonian Institution. He was made Assistant Director of the National Museum in 1881, and Assistant Secretary of the Smithsonian Institution, in charge of the National Museum, in 1887. He also held for a time, after the death of Professor Baird, the post of United States Commissioner of Fish and Fisheries, and was connected officially with every exposition save one in which the United States participated from 1876, either at home or abroad.

Careful biographies of Mr. Goode have been prepared by others, and a memorial volume is now printing which will give a record of his life and work. It will be fitting before this Society to speak of him in but a general way, since any detailed account would far transcend the limits which the Society allots to biographies of its members.

Mr. Goode was a naturalist of the broad old-fashioned type. Although he specialized in fishery work and in later years on the fauna of the deep seas, he always stood for catholicity; he thought that every scientific man should have his foundations laid on the old academic lines, and viewed with a certain disfavor the highly specialized methods of the modern biologists.

Working under unfavorable conditions, in an unsuitable building, and with great restrictions in funds, he yet became one of the foremost Museum administrators of his time, combining to the full a sympathy with the special student and the general visitor, bringing to bear his fine artistic instincts as to color and form, developing a system of labeling which has nowhere else been equaled, and being the first to reduce to a method the principles of Museum administration.

He was a lover of books, of prints, of autographs, and all these he collected systematically and successfully. He was an accomplished musician, and collected American linguistic dialectic forms with such assiduity that his manuscript of these is probably the largest in existence.

He was an American deeply interested in the welfare of the whole country, a devoted student of the writings of the Fathers of the Republic, a hater of all injustice, greed, and

oppression. He had an especial interest in Virginia history and genealogy, and made substantial contribution to both subjects. He was the pioneer historian of American science.

He was prominent as an organizer of scientific, historical, and patriotic societies. I can say of my own knowledge that in no society of which he was a member did he have a keener interest than in this, the Philosophical Society of Washington. He was attracted by its traditions, it is true; but Mr. Goode was not a man to live in the past; it was the breadth of scope of this Society, the fact that it was the only common meeting ground in Washington of men interested in all science—in all knowledge, in fact, since science is a restricted word—that caused him to impress upon all his colleagues and friends the necessity of preserving our organization on a broad foundation in consonance with the purpose of its founders.

He was elected a member of the Society on January 31, 1874; a member of the General Committee December 19, 1885; Vice-President December 21, 1887, and was President for the year 1893.

The papers he read before the Society were:

"The Sword Fish and its Allies," April 18, 1881.
"The Fisheries of the World," October 7, 1882.
"Fisheries Exhibitions," March 29, 1884.
"The Systematic Care of Pamphlets," November 21, 1885.
"The Distribution of Fishes in the Oceanic Abysses and Middle Strata," April 24, 1886.
"Museum Specimens Illustrating Biology," May 22, 1886.
"The Geographical Distribution of Men and Institutions in the United States," February 12, 1887.
"Origin of Our National Scientific Institutions," March 1, 1890.

And as President delivered an unpublished address on "What has been done for Science in America."

G. Brown Goode.

Born 1851, February 13--Died 1896, September 6

The memorable 400th meeting of the Society was held under his presidency.

But above and beyond all, Mr. Goode was a man—wise, kind, strong, forbearing—a man who could bravely lead and follow loyally; the strength, beauty, and sweetness of whose disposition made other men his own peculiarly; with such vast learning, keen insight into men and affairs, grasp on everything that related to the advancement of the highest interests of the country, and willingness to give his time, his mind, his life, to the advancement of those interests, as to entitle him to be classed among the great men of the days in which he lived; if I may speak personally, a man whose place no other friend can supply. It is three years and more since he was laid to rest, and not a day has passed that I have not missed him, have not grieved for him, have not felt my life was poorer without him.

CYRUS ADLER.

EDWARD GOODFELLOW.

1828–1899.

[Read before the Society, December 9, 1899.]

Mr. Edward Goodfellow, the subject of this sketch, was my friend and comrade for many years. I was familiar with his aspirations, and know only too well the failure of his hopes in the undeserved misfortune that overtook him in after life, in his separation from the work he had served so faithfully and well for more than a generation; and yet I can do but scant justice to the man, his gentle nature, high sense of honor, and the many traits that compel us to call a man our friend, for diffidence was also a pronounced characteristic, and yielded only when assailed in the briefer hours of a ripened friendship.

Mr. Goodfellow was born in Philadelphia, February 23, 1828, and died in Washington, May 7, 1899. He received his

primary education in a private school of which his father was the principal, and subsequently attended the school for classics under Joseph Engles, and the University of Pennsylvania, graduating from the latter institution in June, 1848. He had taken a great interest in Greek during his college course and won at least one prize for that tongue, and was honored at his graduation by the appointment to deliver the Greek salutatory. His decided inclination to literature led him to a warm friendship with Prof. Henry Reed, the professor of English literature at the university, which ended only with the Professor's death.

It was through Professor Reed's influence that Mr. Goodfellow was appointed on the Coast Survey, in August, 1848, the Professor having been a warm friend of Alexander Dallas Bache, then the Superintendent of the Survey. His first appointment appears to have been a clerkship, but in December, 1849, we find him as aid in the Superintendent's party on the measurement of the Edisto base in South Carolina. He was shortly afterward transferred to astronomical work, and during the continuance of his service on the Coast Survey was, with few interruptions, engaged upon this class of work until his assignment to duty at Washington as executive officer to the assistant in charge of the office, April 1, 1873.

In 1861, at the outbreak of the Civil War, Mr. Goodfellow served for a year as assistant in charge of the office, being relieved of that duty at his own request. In August, 1864, he resigned and accepted a commission as captain in the Forty-fifth regiment of United States volunteers, but was unfortunate in receiving a sunstroke shortly after his appointment that prevented his entering upon an active campaign. He therefore secured his discharge, and in November, 1864, was reappointed an assistant in the Coast Survey. During Mr. Goodfellow's long career on the field-work of the Survey he had charge of many important stations and assisted in some of the operations of the Survey that have become historical. In 1866–1867 he was at Hearts Content, the American end of the first exchanges of time by cable to determine difference

of longitude from Greenwich. In 1868 he accompanied the Coast Survey expedition to Labrador for observing the total eclipse, and in 1872 was at St. Pierre, Miquelon island, again on cable longitude work.

In 1882 Mr. Goodfellow was assigned the duty of preparing the Annual Report of the Superintendent, to which was subsequently added the editorial work for all the publications of the Survey, continuing upon this duty until his separation from the Survey, in August, 1894.

The last years of his life were a continued struggle. At first he manfully attempted new work, at best a difficult task even in the prime of manhood; but the growing financial depression of the period prevented success, his cheerfulness left him, and finally he was only too glad to accept a subordinate position in the National Museum, where he diligently labored until the unfortunate accident that caused his death.

Mr. Goodfellow was a founder of the club in whose hall we hold this memorial, and was a member of a number of scientific societies, to which he occasionally made contributions. He was an earnest worker, honest and sincere in his friendships, too retiring for his own welfare, but those who knew him well, I feel assured, must always carry a soft spot in their hearts in tender remembrance.

HERBERT G. OGDEN.

HENRY ALLEN HAZEN.

1849–1900.

[Read before the Society, March 3, 1900.]

On the evening of Monday, January 22, 1900, Prof. Henry Allen Hazen, while riding rapidly on his bicycle, hastening to his night work at the Weather Bureau, collided with a pedestrian and was dashed to the ground. After lying unconscious for twenty-four hours, he expired on the 23d.

Professor Hazen was born January 12, 1849, in Sirur, India, about 100 miles east of Bombay, the son of Rev. Allen Hazen, a missionary of the Congregational Church. He came to this country when ten years old, and was educated at St. Johnsbury, Vermont, and at Dartmouth College, where he was graduated in 1871. After this he removed to New Haven, Connecticut, and for four years subsequent was assistant in meteorology and physics under Prof. Elias Loomis. He was also privately associated with the latter in meteorological researches and the preparation of many of the Contributions to Meteorology published by Professor Loomis, some of which bear evidence of the reflex influence of the pupil on the teacher.

In the spring of 1881, when the present writer first saw Professor Hazen in New Haven, the latter showed such an earnest interest in meteorology as to justify recommending him to the position of computer in the study-room, which was then being organized by Gen. W. B. Hazen, the Chief Signal Officer, for the purpose of developing the scientific work of the Bureau, as a necessary adjunct to its important practical work. After his entry, May, 1881, into the meteorological work of the Signal Service, Professor Hazen took a prominent part in this field. The works specially assigned to him were by no means sufficient to absorb his energies, and we find him writing and publishing on many subjects, such as barometric hypsometry and the reduction to sea-level, the testing of anemometers, the study of tornadoes and the theories of cyclones, atmospheric electricity, balloon ascensions, the influence of sun spots and the moon, the danger lines of river floods, the sky-glows and the eruption of Krakatoa. His enthusiastic advocacy of the importance of the balloon to meteorology was very highly appreciated. His five ascensions (1886, June 24–25; 1887, June 17 and August 13; 1892, October 27) undoubtedly gave very accurate temperatures and humidities. After the death of General Hazen and during the administration of General Greely the computers of the study-room became junior professors at

a higher salary and were assigned to official duties of a broader aspect. In the course of such duties Professor Hazen frequently took his turn as forecast official and as editor of the *Monthly Weather Review*, while also acting as assistant in the Records Division. In July, 1891, in accordance with the terms of the transfer to the Department of Agriculture, he was appointed one of the professors of meteorology in the Weather Bureau, where he was at once assigned to regular and congenial duties in the Forecast Division.

Having shown that the Hazen thermometer shelter was much better than the large, close double-louvered one formerly used, his form was adopted by the Weather Bureau in 1885 and still remains in use. His experimental work with the sling psychrometer and dew-point apparatus was executed with great care and refinement, but his resulting psychrometer formula differs from those in current use, in that he rejected the important term depending on the barometric pressure.

Professor Hazen was a frequent contributor to meteorological and other scientific journals. He was one of the supporters of *Science* during the years 1882–1889, and of the *American Meteorological Journal*, 1884–1896. He also published independently his "Meteorological Tables" and "The Tornado," and possibly other works. A complete list of his published writings would include about eight hundred titles.

It must be confessed that a peculiar temperament sometimes led him to beliefs and statements in scientific matters entirely untenable at the present day, but to which he adhered with such pertinacity that to some he occasionally appeared obstinate and headstrong. This was simply a result of the intense earnestness of his own convictions, which so completely absorbed his mind that there was no place for further considerations. However, the amiability of his character always prevented any enduring unpleasant feeling between himself and his associates.

In addition to his work in meteorology, Professor Hazen,

like his master, Professor Loomis, was greatly devoted to the study of family history and genealogy, and it is understood that his collections in that line are in proper shape for the publication of a large volume. Certainly the widespread family to which he belonged includes very many distinguished names in theology, literature, commerce, and military matters. A great tenacity of purpose, independence of character, boldness in the defense of personal convictions and energy of execution are prominent characteristics of all the families bearing the name of our departed colleague. Himself unmarried, he cared lovingly and dutifully for relatives who depended on him. His heart was as many-sided as his intellect.

CLEVELAND ABBE.

CHARLES HUGO KUMMELL.

1836–1897.

[Read before the Society, May 28, 1898.]

Charles Hugo Kummell was born August 26, 1836, in Wetler, Kurfürstenthum, Hessen, Germany, and died in Washington, D. C., April 17, 1897.

He received his early education at home, from his father and from private tutors. At the age of fourteen he entered the Technological Institute at Cassel, and two years later, in 1852, entered the University at Marburg. He early showed a strong liking for classical music, and his spare moments while at the university were given to the study of Mozart and Beethoven.

In August, 1866, he came to the United States and settled at Norfolk, Virginia, where his elder sister was then living. Here he lived for nearly five years, finding occupation as a teacher of music. In April, 1871, he secured employment with the United States Lake Survey, and was thereafterward employed as a computer in the office at Detroit, Michigan,

until the completion of that survey, in 1880. He then came to Washington and entered the office of the Coast and Geodetic Survey as a computer, a position which he held for seventeen years, till his death, of pneumonia, in April, 1897.

Joining the Philosophical Society in March, 1882, he became a regular attendant at its meetings and a contributor to its program up to the very last. During his fifteen years of membership he presented to the Society and its Mathematical Section eighteen communications—the first June 17, 1882, the last on April 3, 1897, just two weeks before his death. All these papers were of a mathematical character, and related for the most part to the theory of errors, elliptic functions, and geodetic problems. In all of these his work is characterized by neatness, thoroughness, and practical application, with examples carefully wrought out. Accustomed to computation, he set forth his results with a fullness of example well adapted to the computer's needs.

Of a retiring disposition, he mingled little in society, but spent his leisure at home, devoting his spare hours to music and mathematics. He married, in Detroit, Michigan, September, 1873, Miss Wackwitz. She, with a son and a married daughter, Mrs. Beresford, survive him.

Marcus Baker.

WILLIAM LEE.

1841–1893.

[Read before the Society, May 23, 1896.]

Doctor William Lee, born in Boston, Massachusetts, March 12, 1841, was the eldest son of William Barlow and Ann (Whitman) Lee. When 13 years of age he came, with his parents, to Washington. Four years later, at the age of 17, he accompanied the military expedition of Captain J. H. Simpson to Utah. On his return to Washington he took up the study of medicine.

In 1861 he was acting medical cadet at the Infirmary (Judiciary Square) Hospital, District of Columbia; in 1862 medical student at St. Elizabeth Hospital; from 1865 to 1867 lecturer and adjunct Professor of Physiology in the Medical Department of Columbian University, District of Columbia, and full professor of the same subject in the same institution from 1872 till his death, in 1893.

In 1863 he graduated M. D. from the College of Physicians and Surgeons, New York, and for two years thereafter was resident physician to Bellevue Hospital. He returned to Washington in 1865 and entered upon the practice of his profession. In 1871 he was co-editor of the National Medical Journal, Washington, District of Columbia. He was a member of the Medical Society and the Medical Association of the District of Columbia; also member of the American Medical Association, of which he was librarian for many years. His fondness for books brought him into association with librarians, and thus we find him librarian of the Medical Society, librarian of the Cosmos Club, of which he was one of the founders, and a diligent worker on the Toner collection, now a part of the Library of Congress, upon which collection he performed valuable work in cataloguing and classifying.

He was a member of the New England Historical and Genealogical Society, of the Sons of the American Revolution, of the American Association for the Advancement of Science, and of the Numismatic Society. He was on the medical staff of the Emergency Hospital, in charge of the section of general diseases, and was on the consulting staff of the woman's clinic.

His interest in coins and medals is shown by his membership in the Numismatic Society and by his collection of medals, which is deposited in the Army Medical Museum and is known as the "Lee Collection." On medical subjects he wrote numerous articles, which were published in the medical journals. He also published an article, "Currency of the Confederate States, 1875," and another on "John Leigh and his Descendants, 1889."

His chief life work, and that which he best loved, was in connection with the Chair of Physiology in Columbian University. Above all else he aimed to *teach* his subject, and in this he succeeded. He was a favorite with both students and professors. With his confreres in the medical profession he stood deservedly high, having been honored with the presidency of both the Medical Society and the Medical Association of the District of Columbia.

In his work he was careful, painstaking, and methodical, as he was in all the relations of life. He was unobtrusive and modest in claiming credit for what he did.

For several years preceding his death he suffered from diabetes, which rendered the performance of his manifold duties more difficult, but he persevered in his work up to his last illness, which was pneumonia following grip. He died in Washington, March 2, 1893.

On April 2, 1885, he was married to Mary Agusta Gadsby (daughter of William Gadsby and Mary Agusta Bruff), but left no children.

D. W. Prentiss.

WALTER LAMB NICHOLSON.

1825–1895.

[Read before the Society, May 23, 1896.]

Walter Lamb Nicholson was born in Edinburg, Scotland, in 1825, and was educated at the high school, where he displayed unusual proficiency in languages and mathematics. At the age of sixteen, upon the death of his father, William Nicholson, one of the founders and for four years honorary secretary of the Royal Scottish Academy, he went to England to study civil engineering, and was employed in the office of the London and Great Midland railroad until 1851, when he came to America to take a position as assistant engineer on railroads in Kentucky and Arkansas. This duty occupied

him until 1856, when he was offered a position in the United States Coast Survey under Professor Bache. There he had charge of the preparation for publication of the records and results of the work of the Survey, his taste and thorough knowledge of mathematics particularly fitting him for a success in this work which was highly appreciated by Professor Bache. On the breaking out of the war his experience as a civil engineer in the South was at once utilized in the preparation of maps for the use of the army.

In 1863, when the Postmaster General asked Professor Bache to recommend some one as topographer of that department, Mr. Nicholson was at once selected, and filled the position for twenty-two years. During the war, and for some time after, this office was one of peculiar importance to the Government, all questions of distance and mileage being referred to it for verification. Here again his knowledge of mathematics and extreme accuracy were of untold value, and are to this day often referred to in the office. He originated and carried into successful operation the use of post-route maps, the value of which was immediately recognized.

Mr. Nicholson was one of the founders of the Philosophical Society of Washington. He enjoyed in a marked degree the friendship and esteem of Professor Henry, and was associated with him in a number of scientific investigations. He was known to both Bache and Henry as a man in every respect worthy of their confidence.

Socially of a kindly and generous temperament, with refined and scholarly tastes, he was thoroughly conversant with the history, the traditions, and the literature of his native land. These were his favorite themes, and he knew how to make them of unfailing interest to his friends.

For some years before his death, which took place at his home in Washington in April, 1895, he was in failing health, but retained his mental faculties to the last.

EDWARD GOODFELLOW.

ORLANDO METCALF POE.

1832–1895.

[Read before the Society, May 23, 1898.]

The name of Orlando Metcalf Poe does not appear among the names of those who in the spring of 1871 requested Joseph Henry to preside at a meeting to be held for the purpose of forming a society having for its object the free exchange of views on scientific subjects and the promotion of scientific inquiry among its members, a meeting which resulted in the organization of the Philosophical Society.

But Joseph Henry was then and until his death a warm personal friend of General Poe, and the latter's personal and social relations with the founders of the Philosophical Society were very close. He was elected a member of the Society in 1874, but long before that time he had been a member of a small club of distinguished men out of which grew the Philosophical Society. This club numbered among its members Bache, Henry, Meigs, Barnard, Newcomb, Hilgard, Chase, and McCulloch. The latter was then Secretary of the Treasury, and later in life, in his published reminiscences, entitled "Men and Measures of Half a Century," he gave an account of the club. He declares that the most delightful hours which he spent in Washington were spent at its meetings. Describing the characteristics of the men composing it, he says that "all of them were interesting men—all well known to each other, and some of them to the public, by their scientific and literary attainments; there was not one who would not have been distinguished in any literary and scientific club in this country or in any other country; there was not a money-worshipper or time-server among them all." * * * "O. M. Poe, whom I knew very well, was one of the youngest members of the club. He was regarded as a young man of great promise, which promise has been fulfilled. He has become, while still in the prime of life, one of the ablest and most distinguished engineers connected with the army."

This casual tribute, from so eminent a source, to the impression which Poe's strong personality created is, however, in one sense misleading. Poe was at that time not merely a man of promise; the record of his life was already more full of things accomplished than fall to the lot of most men, as will appear from the brief statement of his career which this sketch permits.

His paternal ancestor was George Jacob Poe, who emigrated to this country from Germany, and who settled in Maryland in 1745. Thence members of the family migrated westward and settled in Ohio, where, in the town of Navarre, Stark county, Orlando Metcalf Poe was born on March 7, 1832. He received his early education at public schools and at the Canton Academy, and was teaching a district school when a fortunate opportunity, which he was quick to seize, enabled him to carry out a long cherished wish to enter West Point as a cadet.

One day while he was in a neighboring town he met, on a passing train, a youth who had been appointed, but who had failed to maintain himself at the Military Academy. Poe, realizing his opportunity, mounted a horse and rode sixty miles to see the member of Congress from his district, from whom he solicited and obtained the appointment to the vacant cadetship. He graduated from West Point in 1856, and served as topographical engineer on the survey of the Great Lakes until the threatened outbreak of the Civil War, when he offered his services to Governor Dennison, of Ohio, who summoned him as soon as hostilities commenced. He assisted in organizing the first Ohio regiments of volunteers, but declined a proffered command because it was then the intention of the War Department to keep the regular army together. Poe, however, suggested to the governor to appoint George B. McClellan, who was then in civil life, to the command of the Ohio troops. He sought out McClellan and introduced him to Governor Dennison, who, acting on Poe's advice, appointed him to the command.

It would be out of place here to give General Poe's mili-

tary record. It will suffice to say that he was made colonel of the Second Michigan volunteers in September, 1861, and brigadier general of volunteers in November, 1862. He served with great distinction, taking part in more than a score of battles. From time to time he received promotion in the regular army, each time for gallant and meritorious services, culminating in the rank of brevet brigadier general in 1865. That he was closely associated with General Sherman for a period of twenty years is alone evidence of the regard in which he was held by that great soldier, on whose staff he served; but the letter, since published, which the retiring General of the Army addressed to him at the close of his military career shows clearly the deep friendship and esteem in which Poe was held by his chief.

Distinguished as General Poe was as a soldier in war, he was no less distinguished as an engineer in time of peace. Of his works as engineer, the construction of Spectacle Reef light-house, in Lake Huron, and the design and construction of the great locks at Sault Ste. Marie are the most noteworthy. It was while he was inspecting a break in the lock just mentioned that he slipped and fell, abrading the skin of his leg. He paid but little attention to the injury, but erysipelas developed, from which he died on Wednesday, October 2, 1895.

To this barren outline of a life of ceaseless activity but little can be added in the allotted space to describe the man and his relation to his family.

In person he was of soldierly bearing, tall and straight, broad-shouldered, and of massive mien. His appearance showed his great physical power, his conversation his wide range of knowledge and sympathetic nature, and the directness of his speech his open heart. Early in his career he won the hand of a worthy helpmate in the person of Eleanor Carroll Brent, daughter of Thomas Lee Brent, of Virginia, a captain in the army. He was married to Miss Brent in Detroit, June 17, 1861. Four children were born to them, but, of these, three died within the last six years of his life,

his eldest son dying but five months before his own death—a series of terrible afflictions which he bore with a soldier's fortitude. His widow and youngest daughter survive him.

His deeds are his best eulogy.

O. H. Tittmann.

CHARLES VALENTINE RILEY.

1843–1895.

Since the shocking death of Professor Riley, on the 14th of last September, very many obituary notices have been published in America and abroad, and every reading scientific man must have become familiar with the details of his most useful life. Perhaps the best of these obituary notices are those by Dr. G. Brown Goode and Dr. A. S. Packard, the first prepared for the Joint Commission of the Scientific Societies of Washington and afterward published in *Science* (n. s., vol. iii, No. 59, February 14, 1896), and the second published some weeks previously, also in *Science* (n. s., vol. ii, No. 49, December 6, 1895).

So full are these two notices, and so particularly complete and appreciative in their estimates of Riley's scientific work and his influence upon American science, that there seems to be almost nothing to be said; yet on account of his early connection with this Society, and the great interest which he always took in its work and in its prosperity, it seems most fitting that at least a brief account of his life and death be presented at this time.

Charles Valentine Riley was born near London, 18th September, 1843, and spent his boyhood there. His father was a clergyman of the Church of England. On his mother's second marriage he was sent to boarding school at Dieppe, at the age of eleven, and later to Bonn, and at the age of seventeen took his fortune in his own hand and came to America. He farmed for a while in Illinois, and then went

to Chicago, where he did journeyman printing, drew portraits, acted as a reporter for one of the papers, and finally became permanently attached to the office of the *Prairie Farmer*, the leading agricultural journal of the West. In 1864 he enlisted in one of the Illinois regiments, and served to the close of the war, returning then to his agricultural editorial work.

While still a mere boy he became greatly interested in the study of insects. He showed me once a note book which he had started at the age of nine or ten years, in which he intended to describe the transformations of all the insects of the neighborhood, and in this book were drawings which indicated a most unusual artistic talent. This interest in insects, in studying their habits and drawing their different stages, lasted through his life, and eventually became his great work. He continued drawing while at school on the continent, and developed so great a talent that one of his instructors advised him strongly to become a professional artist.

While on the farm in Illinois his attention was first drawn to the damage which insects do to cultivated crops, and he subsequently owed his position on the *Prairie Farmer* to articles which he had written and handed in, in which he suggested new remedies for crop pests. As an attaché of this great agricultural newspaper he attended the gatherings of farmers, and particularly the meetings of the prominent Illinois Horticultural Society. In this way he became acquainted with the leaders in agriculture and horticulture, and made the acquaintance of Benjamin D. Walsh, a man of remarkable character and great ability, of English university education, who was in 1867 appointed the first State entomologist of Illinois. Walsh exercised a great influence upon Riley's future. Together they founded and edited the *American Entomologist*, and when, in 1868, the State of Missouri passed a law providing for a State entomologist, through the influence of Walsh and prominent Illinois agriculturists, led by the value of the work which he had already done, Riley was chosen to fill the place.

His great opportunity had now come. At this time he was twenty-five years of age. He entered upon his new duties with tremendous enthusiasm and long before the completion of his series of nine annual reports his name was known in all parts of the civilized world as the foremost living economic entomologist. In this work Riley followed in the main the methods which he had learned from Walsh. His early reports show a touch of the discursiveness which forms the only blemish in Walsh's published writings; but this bit of discursiveness was just enough to make them thoroughly readable to the agricultural population. His ability as a delineator of insects was unsurpassed, and his reports from beginning to end were filled with pictures of insects of lifelike character and marvelous scientific accuracy. Their equals had hardly before been seen.

The reports were almost entirely based upon original observations. He kept abreast with the scientific thought of the times, the field was almost entirely his own, and he made many discoveries of far-reaching practical and scientific importance.

When we stop and consider that this Missouri work, which has been called epoch-making in its character, was accomplished by Riley between the ages of 25 and 34, and that he did it single-handed, then we begin to realize that we are dealing with a most extraordinary man.

Toward the close of his term of office in Missouri the disastrous outbreak of the Rocky Mountain locust or "grasshopper" in Kansas, Colorado, and Nebraska attracted his attention to this line of investigation, and in 1876, through his efforts, the United States Entomological Commission was founded by Congress and placed under the Interior Department for the purpose of investigating this insect. This work brought him to Washington, and two years later he was appointed Entomologist to the Department of Agriculture in place of Townend Glover, who had held that position for many years, but whose health had at that time failed. With the exception of an interval of nearly two years, Riley held

the position, called by courtesy that of United States Entomologist, from that time until June, 1894. The Entomological Commission was continued, and published bulletins and reports down to 1884.

In the Department of Agriculture Riley was a leader. His interest in agricultural science extended beyond the boundaries of his own specialty, and he was practically responsible for many reforms and for many innovations of great value in the department. He was the warm personal friend of two of the Commissioners, and his advice had great weight with them.

Aside from his work during these years in the Department of Agriculture, he was an active man elsewhere. He became a member of the Philosophical Society when he first came to Washington, and was afterward prominent in the work of the Biological Society, of which he was president for two years. He was the founder and first president of the Entomological Society of Washington, and one of the founders of the Cosmos Club. The scientific and agricultural societies of which he was a member are so numerous that they cannot be listed here. Many of them were foreign, and he was most prominent in many American societies.

One of the saddest facts connected with his early death is associated with his plans for future work. In 1886 he gave his collection of insects, amounting to 115,000 specimens, to the United States National Museum to help form a Department of Insects, and held the office of Honorary Curator of that department until his death. It was his intention after his resignation from the Department of Agriculture, in 1894, to devote the remaining years of his life to pure scientific research, and he rejoiced at having thrown off the cares of routine work connected with the office which he had previously held in the department. His death in little less than a year thereafter seems a shocking example of the irony of fate, and certainly it occasioned a loss to pure science the extent of which cannot be estimated:

It is safe to say that in the comparatively new science of

economic entomology no man's name stands on the same plane with that of Riley. Outside of economic entomology, his contributions to science were many and of great value. He possessed the friendship and confidence of many of the leaders in scientific thought. Honors came to him abundantly from the time when he first became prominent as a writer. He died at the comparatively early age of 52, after having accomplished an amount of work which, when one sums it up, would seem sufficient to occupy the lifetime of many men of ordinary capacity.

Mentally he was one of the most active men of the age. He was many-sided and of broad interests. Had he been a man of university training and of exceptional advantages, the record of his life would still have been wonderful. As it is, it is practically without parallel.

L. O. HOWARD.

SAMUEL SHELLABARGER.

1817–1896.

[Read before the Society, March 31, 1900.]

Samuel Shellabarger was born December 10, 1817, in Mad Run township, Clarke county, Ohio, and died August 6, 1896, in Washington, D. C.

On his father's side he descended from a Swiss family whose lineage is said to have been traced back to the fourteenth century. On his mother's side he was of Irish descent.

He was the eldest in a family of eight children, of whom he outlived all save one, John Shellabarger, of Beatrice, Nebraska. His early life was spent on his father's farm and at the district school, from which he went to Oxford, Ohio, and attended Miami University, where he graduated in his twenty-fourth year, in 1841.

For a profession he chose the law, and this profession, interrupted by intervals of public service, he pursued to the

end with diligent application, unswerving rectitude, and distinguished success. He studied law with the Honorable Simson Mason, and was admitted to the bar in Troy, Ohio, in 1846, in his twenty-ninth year.

Four years later, in 1850, we find him a member of the legislature of his native State, and thus serving his law-making apprenticeship in the session at which the present constitution of Ohio was framed and adopted. He continued his service in the State legislature for several terms, and in the fall of 1860 was promoted by election to membership in the Thirty-seventh Congress from the Springfield district.

Thus he began his career in the national legislature in the stormy days of 1861. Ending his term in March, 1863, he was not returned. Two years later, however, he was again chosen, and served as a member of the Thirty-ninth and Fortieth Congresses, from 1865 to 1869, thus participating in the exciting controversies over reconstruction and impeachment. It was in the debate upon reconstruction that his strength as lawyer, debater, and orator shone forth with their greatest clearness. Section 6 of the reconstruction act of March 2, 1867, as it now stands in the statute book, was drafted by him as an amendment late at night on February 20, 1867, immediately offered, and adopted without change. The original manuscript is preserved as a family heirloom.

It was in this same year that Alaska was purchased, a measure which Judge Shellabarger, as he was usually called, opposed because, said he, "Those nations which have been most compact and solid have been most enduring, while those which have had the most extended territory have lasted the shorter time."

At the close of his third term in Congress, President Grant appointed him, in 1869, United States Minister to Portugal. He accepted the appointment and went to his post, but resigned it in December of the same year and returned home. He was for the last time elected as a Member of Congress in 1870, and served during the Forty-second Congress, 1871–1873, but declined a renomination.

The earliest movement toward a reform in the civil service, it will be remembered, occurred early in the seventies, under President Grant, and one of the compliments paid to Judge Shellabarger's ability and integrity was his selection as a member of that earliest Civil Service Commission.

From 1848 to 1874 Judge Shellabarger's home was in Springfield, Ohio. In 1875, however, he moved to Washington and formed a law partnership with Honorable Jeremiah M. Wilson, a former associate in Congress—a partnership which lasted till death.

His relations to this Society were not intimate. He became a member on April 10, 1875, shortly after taking up his residence in Washington, and retained his membership to the last. In appearance, as we saw him in the afternoon of his life, he was a tall man, of large frame, deliberate in his walk and manner, slightly bent, and having the appearance of a scholar or philosopher rather than that of a man of affairs.

He married, May 25, 1849, Elizabeth Henrietta Brandriff, of Troy, Ohio. She, with two daughters, Miss Anna A. Shellabarger, of Washington, and Mrs. J. H. Young, of Springfield, Ohio, survive him.

MARCUS BAKER.

WILLIAM BOWER TAYLOR.

1821–1895.

[Read before the Society, May 23, 1896.*]

William Bower Taylor, born in the city of Philadelphia May 23, 1821, was the son of Colonel Joseph Taylor and Anna Farmer Bower, both of Philadelphia.

Colonel Taylor was a bookbinder, and in 1821 was elected colonel of the Seventy-ninth regiment of Pennsylvania mili-

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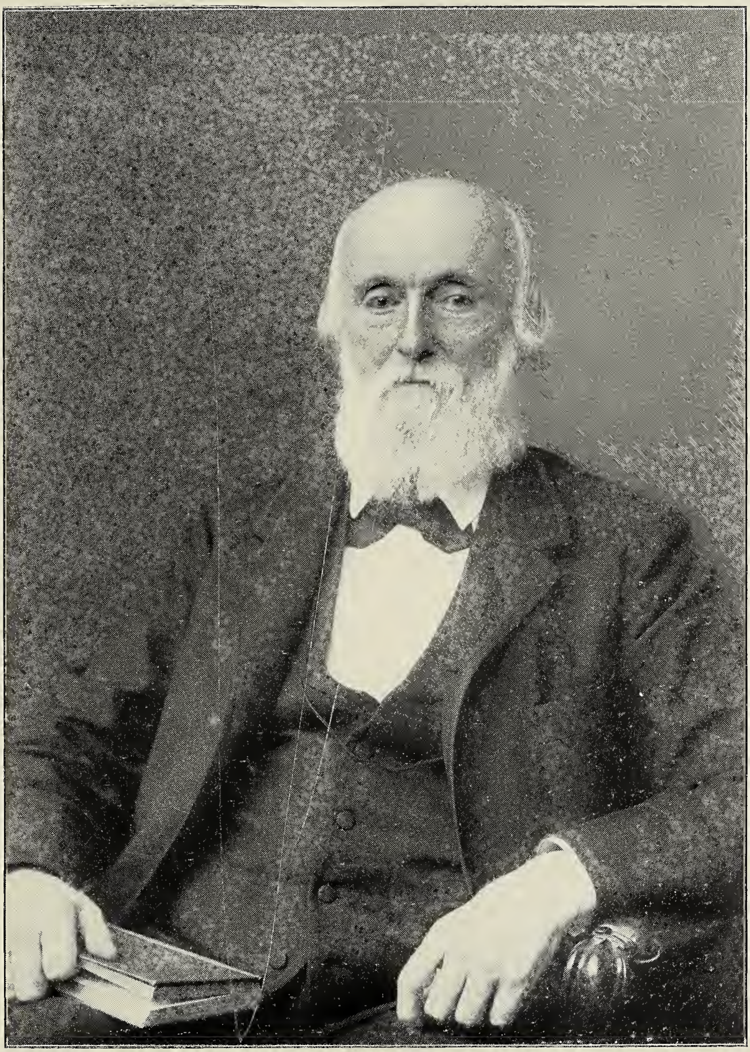
* This memoir, as here printed, is an abridgement of the paper as read. The memoir, *in full*, was published in Smithsonian Institution Annual Report for 1896, vol. 1, p. 645.



From photograph by Gutekunst about 1885

Very respectfully
Wm. B. Taylor.

Born 1821, May 23--Died 1895, February 25

tia, which commission he held for seven years. He was well educated, early in life became interested in politics, and was elected to the Pennsylvania legislature. Having removed to his farm near Millville, New Jersey, for the benefit of his health, he was in 1843 elected to the legislature of that State.

William's mother died while he was quite young. His father provided him with a liberal education, sending him to a Baptist college at Haddington, Pennsylvania, then to an academy taught by Professor Walter R. Johnson, and subsequently to the University of Pennsylvania. Professor Johnson, one of the most learned men of that time, was secretary of the Academy of Natural Sciences, member of the National Institute, professor of physics and chemistry in the University of Pennsylvania, and an able writer on scientific and technological subjects.

In 1835–1836 several gentlemen formed a society, with the name of The Franklin Kite Club, for the purpose of making electrical experiments. For a considerable time they met once a week at the Philadelphia City Hospital grounds and flew their kites. These were generally square in shape, made of muslin or silk, stretched over a framework of cane reeds, varying in size from 6 feet upward, some being 20 feet square. For flying the kites annealed copper wire was used, wound upon a heavy reel 2 or 3 feet in diameter, insulated by being placed on glass supports. When one kite was up, sometimes a number of others would be sent up on the same string. The reel being inside the fence, the wire from the kite sometimes crossed the road. Upon one occasion, as a cartman passed, gazing at the kites, he stopped directly under the wire and was told to catch hold of it and see how hard it pulled. In order to reach it he stood up on his cart, putting one foot on the horse's back. When he touched the wire the shock went through him, as also the horse, causing the latter to jump and the man to turn a somersault, much to the amusement of the lookers on, among whom was Taylor.

It was this incident and others of a similar character connected with the kite club that turned his youthful mind to

science, and especially to electrical phenomena. He made a number of kites himself and also endeavored to make a flying machine. He made a clock wholly of wood, which kept good time.

In 1836 Taylor entered the University of Pennsylvania, became a member of the Philomathean Society, and later its moderator or president. He was graduated in 1840 and commenced the study of law at the university and also in the office of Mr. Rawle, an eminent attorney. He was admitted to the bar of Philadelphia November 15, 1843.

His retiring disposition, studious habits, stern integrity, and high sense of honor were not conducive to securing many clients, and he looked with aversion on the practices of attorneys who were willing to sacrifice truth to gain an unrighteous cause. After four years' experience of an unsatisfactory character as a lawyer, in November, 1848, he became an assistant in the drug store of his brother Alfred, on Chestnut street, near Ninth, and remained there until February 1, 1853.

By special invitation of his cousin, Mr. William Ellis, who was in charge of the navy yard in Washington, he accepted the position of draftsman in the yard February 17, 1853, and a few months later became foreman of the engineer and machinist department. He filled this position acceptably until his resignation, December 31, 1853, receiving a letter from Chief Engineer Henry Hunt, U. S. N., expressing "great regret in his leaving the situation wherein his services and knowledge had been valuable and his deportment most gentlemanly."

In May, 1854, he was appointed by Hon. Charles Mason, Commissioner of Patents, to a temporary clerkship, and on the 1st of April, 1855, was made an assistant examiner in the division under Prof. George C. Schaeffer, the eminent chemist, engineer, and general scientist. Dr. Schaeffer used to relate of this appointment that, finding himself in need of an assistant, he was told by the Commissioner that a young man was in consideration for the place who seemed intelligent and capable, but spoke doubtfully as to his own qual-

ifications for the work. "Then please appoint him at once," said Dr. Schaeffer; "he will be just the man I want." The augury was abundantly fulfilled, and was the beginning of a cordial lifelong friendship between the two men, amid various strong differences of opinion. Their debates on matters of high interest were remembered as contests of giants by their hearers.

Mr. Taylor was appointed principal examiner on November 10, 1857, in the class of firearms, electricity, and philosophical instruments. His early legal education and practice fitted him admirably for the position of examiner and enabled him for more than twenty years fully to meet the requirements of an office which Commissioner Mason declared should command the highest order of talent, "where all learning connected with the arts and sciences finds an ample field for exercise and questions of law that tax to their uttermost the abilities of the most learned jurists;" and another Commissioner, Judge Holt, said: "The ability and requirements necessary to a proper discharge of the duties of an examiner must be of a high order, scarcely less than those we expect in a judge of the higher courts of law."

In 1873, the temporary position of librarian being vacant, Mr. Taylor was detailed to this service on account of his extensive information, and was of great assistance to the examiners through his ability to give them references to aid in making up reports of applications for patents.

The Patent Office library was indeed a grand school of instruction and a mine of inexhaustible wealth for a scientific inquirer. Designed as a collection for reference in the examination of applications for patents, in order to determine the question of novelty of invention, it has grown mainly in the direction of technological publications, including full sets of the periodicals devoted to special industrial art and all the more important treatises on machines, arts, processes, and products, in the English, French, and German languages. Besides this, there are the records of foreign patents of inestimable value.

In 1876 Congress provided for the permanent appointment of a librarian in the Patent Office at a much lower salary than that of an examiner, and as Mr. Taylor still held the appointment of principal examiner, he was not an applicant for the new position, which was filled by a political appointment. Mr. Taylor then expected to be restored to his former duties as examiner; but by reason of smaller congressional appropriations, which necessarily reduced the number of appointments, he was unfortunately legislated out of office.

In a letter dated December 6, 1876, in relation to this matter, Professor Henry remarks: "Mr. Taylor, I can truly say, without disparagement to any officer of the Patent Office, is, for extent of knowledge and practical skill in reporting on the originality of inventions, without a superior in the office. He has long been a collaborator of the Smithsonian Institution, is a member of the Washington Philosophical Society, and has achieved an extended reputation as an active contributor to science by his publications. His separation from the Patent Office I consider a public loss, and justice to himself and the interests of the inventors require his restoration."

In a private note to a prominent Senator, Professor Henry commends Mr. Taylor to his "special attention," and says: "He is held in the highest estimation by all who know him and can appreciate his character. He is not only a gentleman of extensive information and refined culture, but is admirably constituted in regard to intellectual and moral qualities."

While Mr. Taylor was librarian he also acted as examiner of interferences—a very important duty. In fact, Prof. Edward Farquhar, his assistant at the time, remarks that "the various functions he discharged in the office were endless. When a committee was needed to revise the whole classification of the office he was one of the leading members. He was perpetual referee and consulting examiner in a general capacity, as necessarily resulted from his extraordinary knowledge and readiness to impart it, supplying more espe-

cially, perhaps, the principles of science and of law than their practical applications. In the Patent Office, as elsewhere, he was a constant fountain of instruction to all."

In 1872 Professor Henry strongly recommended Mr. Taylor, without his knowledge, for a chair in one of our leading colleges, as one "who from the clearness of his conceptions and the lucidness of his expositions has the elements of an excellent teacher."

Other occasions offered for the employment of Mr. Taylor as a teacher or professor, but he always shrank from assuming the duties of a public instructor and preferred the retirement and privacy of closet study and editorial impersonality.

Mr. Taylor was one of the founders of the Washington Philosophical Society, which grew out of the Saturday Club just alluded to. He signed the call for the first meeting, requesting Professor Henry to preside, March 12, 1871, and on the organization of the Society, March 13, 1871, was elected a vice-president. This office he held until December 17, 1881, when he was elected its fourth president. Between 1871 and 1881 he had presided at forty-five meetings of the Society. His first paper was presented June 10, 1871, "On the Nature and Origin of Force," and was published in the Smithsonian Report for 1870, which was issued late in 1871. At almost every meeting of the Society he either presented an original communication on astronomical, mathematical, or physical subjects, or discussed with freedom, clearness, and marked ability the papers of others. Among his most important addresses before the Philosophical Society was one in 1878 on the "Life and Scientific Work of Joseph Henry." This work was peculiarly agreeable to him as an ardent admirer and strong advocate of Henry's policy, his warm personal friend and intimate associate, and of whom he speaks thus: "Few lives within the century are more worthy of admiration, more elevating in contemplation, or more entitled to commemoration than that of Joseph Henry."

On the 5th of May, 1882, he made a report as chairman of a joint committee on the Philosophical, Biological, and

Anthropological societies, favoring a scheme of consolidation or union of the scientific societies of Washington, an event which, after a lapse of thirteen years, has only recently been in some degree accomplished.

In February, 1883, a Mathematical Section of the Philosophical Society was organized, of which he became one of the leading spirits, taking part in every meeting, and on March 24, 1886, he was elected its chairman. On the 23d of October, 1886, he was elected to the general committee of the Society, which position he held until his death, giving to every detail of business the same attention he did to solving the greatest problem of nature.

To the *Journal* of the Franklin Institute, of which society he was long a member, he contributed, in 1876, a paper on "Physics of the Ether," consisting principally of a review of a work by S. Tolver Preston, of London, as well as numerous brief notices or reviews. In the *American Journal of Science and Art*, New Haven, he published a paper in 1876 on "Recent Researches in Sound," and in 1885 "On the Crumpling of the Earth's Crust."

His "Kinetic Theories of Gravitation" was published by the Smithsonian Institution in 1876. An editorial in the *American Journal of Science* refers to this work as "a valuable historical résumé of the various attempts that have been made by the most eminent philosophers to account for the phenomena of gravitative attraction from the time of Newton to the present day, concluded by a vigorous criticism of the leading theories, in which the author, passing over the consideration of the statical method of explaining gravitation by pressure, finds that kinetic systems are essentially of two classes—the hypothesis of emissions or corpuscles, and the hypothesis of fluid undulations—and proceeds to show that neither form of either hypothesis can satisfy the two Newtonian conditions of a scientific theory—verity and sufficiency."

He became a member of the American Philosophical Society of Philadelphia on the 19th of October, 1877, but does not appear to have contributed to its transactions.

He was elected a member of the American Association for the Advancement of Science at its twenty-eighth annual meeting, in August, 1880, and at the meeting of August, 1881, was made a fellow of that society. The only paper he contributed to the proceedings of this Society was on "A Probable Cause of the Shrinkage of the Earth's Crust."

On leaving the Patent Office he was engaged by Professor Henry to edit his researches on "Sound" and "Illuminating Materials" for the reports of the Light House Board, and in 1878 was appointed by Henry as an assistant in the Smithsonian Institution, a position which he continued to hold for seventeen years, until his death.

On the death of Professor Spencer F. Baird, Secretary of the Smithsonian Institution and United States Commissioner of Fisheries, August 19, 1887, the Washington Philosophical Society, as the senior of the Washington scientific societies and the one with which Professor Baird had been most closely connected, took initial steps in arranging for a joint meeting to commemorate his life and services. To Mr. Taylor was assigned the theme of "Professor Baird as an Administrator," and on account of an intimate knowledge of his great work in the Smithsonian he was eminently fitted to discharge the duty assigned him. His eulogy of Professor Baird was published in the bulletin of the Philosophical Society, vol. X, 1888; also in the Smithsonian Miscellaneous Collections.

He was president of the District of Columbia Alumni Association of the University of Pennsylvania, and presided at its annual banquets.

During the life of Professor Henry no formal office existed as "editor" of the Smithsonian publications. Every article submitted for publication was carefully examined by Professor Henry himself, all doubtful points discussed with the authors, and every line closely scrutinized in the proof-sheets, independent of, and in addition to, the examination made by his assistants. Mr. Taylor's distinctive labors as "editor" commenced with Professor Baird's accession to the secretaryship.

The most important duty Mr. Taylor performed as editor while at the Smithsonian was the collection and publication of the Scientific Writings of Professor Henry. To this labor of love, for which he was perhaps better fitted than any other person, he gave a year or two of untiring devotion.

Mr. Taylor enjoyed good health nearly the whole of his life, though for many years he had not taken the customary leave of absence from office, for rest and recreation. An attack of the grip in 1894, however, seemed to enfeeble him and he never regained his former vigor. His last illness was brief. After much suffering from an incurable malady, and submitting to a surgical operation, he died in Washington on February 25, 1895, in the seventy-fifth year of his age, and his remains were buried in Woodlawn Cemetery, Philadelphia, his native city.

> "O, good old man! how well in thee appears
> The constant favour of the antique world,
> When service sweat for duty, not for meed!
> Thou art not for the fashion of these times,
> Where none will sweat but for promotion."

JOSEPH MEREDITH TONER.

1825–1896.

[Read before the Society, January 9, 1897.]

To commemorate, however briefly, the talents and characteristics of those who have gone from among us is due alike to this Society and to the memory of the departed.

Our late associate, Dr. Joseph Meredith Toner, filled during more than forty years an increasingly marked and influential position in the city of Washington. Born at Pittsburg, Pennsylvania, April 30, 1825, he died at Cresson, Pennsylvania, July 30, 1896, while sitting in his chair, during a brief summer vacation. His early training was in the public schools, and later at the Western Pennsylvania University and at St. Mary's College at Emmitsburg, Maryland, though

his only degrees of graduation were from the Medical College at Woodstock, Vermont, in the year 1850, and the Jefferson Medical College, Philadelphia, in 1853.

Dr. Toner inherited from his parentage, which was of the good old solid stock of Pennsylvania farmers, an ample physical frame and an excellent constitution. His temperament was cheerful and hopeful, his manner winning, and his sunny smile is remembered as a marked personal characteristic. He very early developed a strong ambition for learning, and having chosen the profession of medicine as his business, he perfected his knowledge of the art by several years of study and practice in western Pennsylvania. Ambitious for a wider field, the young practitioner removed to Washington city in 1855, and soon acquired a large and remunerative practice. His genial, hearty manner came to the invalid like a ray of sunshine, infusing hope and pleasure. During the Civil War period of 1861–1865 he did much gratuitous service in the hospitals. At the same time his active zeal was devising aid toward the establishment of institutions of charity in our city, and Providence Hospital, two orphan asylums, and in later years Garfield Hospital owe very much to Dr. Toner's activity in their foundation, and gratuitous medical aid to some of them for a long series of years. He was long a leading member of the board of managers of the Government Hospital for the Insane at St. Elizabeth's, and became president of the Medical Society of the District of Columbia, and of the American Medical Association.

He established the "Toner Lectures" in 1872 by a fund of $3,000, one-tenth of the income of which was added to the principal annually, while nine-tenths went to compensate skilled lecturers on some newly developed feature of medical science. He also gave annual medals for scientific essays by students of Jefferson Medical College and Georgetown University.

But it is chiefly Dr. Toner's labors as a writer and a collector of books that enlist our attention. From the year of his arrival in Washington to the time of his decease, he was

ever a vigilant and intelligent book-buyer. Though his earlier purchases were of medical and hygienic literature, he soon grew into a zealous collector of local history and biography. In his later years he devoted much time and money to the collection of the widely scattered biographic notices of American physicians, which expanded into a passion for sketches of the lives of all Americans. In this he cultivated an almost neglected field, by seeking to accumulate from a wide range of newspapers, magazines, etc., all the obituary and biographic portions. These he had mounted on manila paper and arranged in alphabetical order for ready reference. These fugitive biographical data are more valuable because not readily found by any ordinary researches.

His zeal as a collector was further exemplified in his great assemblage of Washingtoniana, or of all the writings of George Washington. Of no American public man, perhaps, are there more extensive written remains than our first President left behind him, but these autograph memorials are unhappily as widely dispersed as they are extensive. Dr. Toner set himself the task of securing for his collection authentic copies of everything which had ever been written by this illustrious man. Not satisfied with copying the long series of Washington's private diaries in the Department of State, and arranging the whole of the writings as published in Sparks's collection, with numerous corrections from the originals, he copied every letter not there found, from the many periodicals which have printed any such during this century or the last one, and made interest with the authorities of historical societies, libraries, and the many private owners of Washington autographs to permit copies to be made of all. Thus he accumulated and arranged in strict chronological order unquestionably the most complete assemblage of the writings of Washington anywhere to be found.

The crowning act that evinced the public spirit and benevolence of our late associate was his gift to the nation, through deposit in the Library of Congress, of his entire collection of books, pamphlets, periodicals and manuscripts. This

generous purpose was consummated in the year 1882, when the donor was in the zenith of his powers, and it was his pleasure and pride to make constant additions to the gift every year during the remainder of his life. The benefaction was recognized by Congress in a special act of acceptance, and a marble bust of the donor, by J. Q. A. Ward, has been placed, with his full-length portrait by Andrews, in the new Library building. The library contains about 28,000 volumes, medical, historical, and miscellaneous, besides a multitude of unbound pamphlets, periodicals, and manuscripts.

It remains to notice briefly the literary and scientific labors of Dr. Toner, and his membership in the Philosophical Society. His habit of mind was instinctively that of an inquirer. He sought to investigate many subjects, and, while he cannot be styled a profound thinker or a discoverer, his researches in many directions were notably thorough.

This was true especially of his historical and biographical labors, and the annotations made by him to the various journals of Washington which he published attest a wide and comprehensive inquiry into all that could elucidate the text. He gathered and published the first extended Dictionary of Elevations of American localities. He invented an ingenious scheme for denoting the relative positions of places on the map, which was adopted by the Post Office Department in its publications.

No full bibliography of Dr. Toner's writings can here be attempted, from lack of space. More than fifty books, pamphlets, and articles in periodicals from his pen were published in his lifetime, of some of which brief mention may be made:

Maternal Instinct. 1864.

Free Parks and Camping Grounds in Summer for Children of the Poor in Large Cities. 1872.

A Dictionary of Elevations, and Climatic Register of the United States. 1874.

Contributions to the Annals of Medical Progress and Medical Education in the United States. 1874.

The Medical Men of the Revolution. 1876.

Notes on the Burning of Theaters and Public Halls. 1876.

Address before the Rocky Mountain Medical Association. 1877.

Washington's Rules of Civility and Decent Behavior in Company. 1888.

Wills of American Ancestors of George Washington. 1891.

George Washington as an Inventor and Promoter of Useful Arts. 1891.

Journal of George Washington's Journey over the Mountains beyond the Blue Ridge, in 1747–'48. 1892.

The Daily Journal of Major George Washington on a Tour from Virginia to the Island of Barbadoes, in 1751–'52. 1892.

Some Account of George Washington's Library and Manuscript Records, and their Dispersion from Mount Vernon. 1893.

Diary of Colonel Washington for August, September, and October, 1774. 1893.

Inaugural Address as President of the Columbia Historical Society. 1894.

Washington in the Forbes Expedition of 1758. 1896.

Dr. Toner was elected a member of the Philosophical Society about a year after its organization, in 1871, and became one of the most regular attendants at its meetings, frequently participating in discussion. Among his contributions were papers on "Earth Vibrations at Niagara Falls," "A Method of Describing Places by the Approximate Position of Geographical Regions," "Coins and Medals," "On the Burning of Theaters and Public Halls," "The Care of Pamphlets," an exhibit of a case of animal malformation, and remarks commemorative of Professor Henry, the President of the Society.

A. R. Spofford.

WILLIAM CRAWFORD WINLOCK.

1859–1896.

[Read before the Society, January 9, 1897.]

William Crawford Winlock, the eldest son of Joseph and Isabella Lane Winlock, was born in Cambridge, Massachusetts, March 27, 1859. His parents were descended from that sturdy Virginian stock that served their country long and faithfully in the War of the Revolution, and then moved westward to found new States beyond the mountains. The father, Joseph Winlock, was born in Shelby county, Kentucky; was educated at Shelby College, in that State; became Professor of Mathematics, U. S. Navy, then Superintendent of the American Ephemeris and Nautical Almanac, and in 1866 was made Director of the Harvard College Observatory. It was during his father's residence at the observatory in Cambridge that young Winlock reached the age when definite tendencies of thought are likely to indicate the line of work that is to absorb the interest of active manhood. Reared under the influences and unconscious training of a cultivated home and in daily contact with men whose zeal and enthusiasm carried them cheerfully through all the laborious routine and details of exacting scientific work, it is not surprising that his interest in the work of the practical astronomer was developed at an early age.

His preparatory training as a student was obtained in the public schools in Cambridge, and he graduated at Harvard College in the class of 1880. During the last years of his college life he improved opportunities for obtaining valuable information regarding the construction and use of several of the principal instruments of the observatory, and under the direction of Prof. W. A. Rogers he gained considerable experience as an observer with the meridian circle.

While studying with Dr. Wolcott Gibbs, of Harvard College, he prepared, from his own observations, a paper "On

the Group *b* in the Solar Spectrum." This paper was published in the "Proceedings of the American Academy," vol. xvi, 1881.

In July, 1880, the number of observers at the Naval Observatory was seriously reduced by the resignation of two assistant astronomers, and the unusual pressure of work at that time made it very desirable to secure efficient assistance without waiting for the usual routine of a competitive examination. As the work was in my own department, I was authorized by the Secretary of the Navy to select the most competent men I could find, to be employed on six months' probation. At my request, Mr. Winlock accepted one of the positions as an assistant astronomer, and reported for duty on August 2, 1880. From the beginning of his work at the observatory until the last day of his service there, he was an important member of the working force.

Quiet and unassuming, he was always courteous, obliging, and mindful of the rights and feelings of all his associates. His cheerful zeal in the prosecution of the duty assigned him left nothing to be desired, and in the nine years of hard and continuous labor as an observer and computer under my direction, I can remember no cause for criticism save a not infrequent caution against overtaxing his physical strength. He continued as an assistant in the work with the transit circle during his entire service at the observatory, and more than nine thousand observations with that instrument constitute a lasting monument to his ability, fidelity, and industry as an observer. As a computer he was methodical and accurate, finding satisfaction only in the best results.

His most important work at the observatory, outside of the continuous routine of meridian work, was a monograph on the great comet of 1882.

This paper of 38 quarto pages, with five plates, appeared as Appendix I in the annual volume of the Naval Observatory for 1880. A large majority of the observations of this comet with the transit circle were made by Mr. Winlock,

who also made the excellent drawings of the different phases of the comet as shown on the accompanying plates.

In the later years of his service at the Observatory he prepared for each annual report of the Smithsonian Institution a paper on the "Progress of Astronomy," giving, in considerable detail, an account of the work of the principal observatories, a list of the discoveries, a brief résumé of the more important astronomical publications, together with a complete astronomical bibliography for the year. This interesting and valuable work was continued from 1885 to 1892.

In 1886 he was appointed Professor of Astronomy in the Corcoran Scientific School of the Columbian University, meeting his classes principally in the evening, and at the time of his death he held the same position, together with a similar professorship in the Graduate School of the same University.

As the years of exacting work passed by, Mr. Winlock lost no interest in astronomical pursuits, which he had early chosen to follow, but he began to realize that the chances for promotion or increase of pay at the Observatory were almost infinitesimal, and that such advantages must be sought in other directions. Accordingly, when the Secretary of the Smithsonian Institution offered him the office left vacant by the death of Dr. J. H. Kidder, he felt that duty to himself and to his family impelled him to accept the position, ardently hoping that he might in his new field find an opportunity to devote a portion of his time to some branch of astronomical investigation.

On May 14, 1889, he was appointed "Curator of International Exchanges" in the Smithsonian Institution. In 1891 his sphere of work was enlarged by assignment as "Assistant in charge of Office," and still later he was made "Curator of Physical Apparatus" in the U. S. National Museum. In this new field of activity his innate liking for scientific work was held in abeyance by the pressure of administrative business, and by his dominant desire to see that every duty was faithfully performed. His buoy-

ant, hopeful spirit, however, led him to find great satisfaction in the systematic, daily attention to the details of the plans that constantly tended to widen the scope of the Smithsonian Institution. To this work he brought all the care, method, perseverance, and courtesy which had made him a valuable assistant and an agreeable colleague at the Naval Observatory.

On December 4, 1880, Mr. Winlock became a member of the Philosophical Society, and at subsequent meetings read several interesting papers. On December 21, 1887, he was elected a Secretary of the Society, and continued to hold that position until his death. Those who have had an opportunity to see his work know the value of his faithful service in that capacity.

On June 2, 1883, Mr. Winlock married Mrs. Alice B. Munroe, of this city, who, with their children, two sons and a daughter, is still living in the family home in Washington.

For several years Mr. Winlock had been aware of the existence of an affection of the heart, which, although possibly serious, had given no sign of immediate danger. With characteristic courage and reticence he went steadily and cheerfully about his daily duties, making no sign, even to his more intimate friends, of the constant burden of the disability. A severe cold in the winter of 1895–'96 reduced his strength and he was unable to regain his wonted vigor before the exhausting heat of the early summer.

With the hope of recovering his strength, a trip to Europe was undertaken, but neither that nor the tender, watchful solicitude of anxious friends availed to restore his flagging energies.

On his return in September he joined his family at Bay Head, New Jersey. There his vitality rapidly failed until Sunday, September 20, 1896, when, surrounded by those he loved, he peacefully lay down the burdens, duties, and joys of this life, passing from our sight, but leaving in our hearts a precious memory of an active, useful life, a kindly, manly, steadfast spirit.

J. R. Eastman.

PROCEEDINGS

OF THE

PHILOSOPHICAL SOCIETY OF WASHINGTON.

FROM THE 429TH MEETING, JANUARY 5, 1895, TO THE 509TH MEETING, DECEMBER 23, 1899.

FROM THE MINUTES.*

429th Meeting. **January 5, 1895.**

President DALL in the chair.

Twenty-five members present.

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* The proceedings here printed were compiled, by the chairman of the Publication Committee, from the Minutes of the General Meetings. The references to places of publication are not recorded in the minutes. To obtain these the following circular letter was mailed to all living persons (except a few whose addresses were not known) who had read papers before the Society:

[JUNE 2, 1900.]

DEAR SIR: From the minutes for the years 1895 to 1899 it appears that you have presented to the Philosophical Society of Washington the following communications:

. . . .

. . . .

Have these papers ever been published; and, if so, where and when? The proceedings of the Society, 1895–1899, are now nearly ready for the press. Added value will be given them by inserting references to places of publication. Will you kindly supply without delay the necessary references to your own papers above cited? If any are unpublished, please so state.

Very truly yours,

MARCUS BAKER,
Chairman Publication Committee.

From the replies to this circular, supplemented by additions and verifications in libraries, the citations of places of publication have been prepared.

Announcement was made of the death, on January 3, 1895, of Mr. Daniel Currier Chapman.

The Auditing Committee elected at the last meeting submitted its report, which was adopted.

REPORT OF THE AUDITING COMMITTEE FOR 1894.

Washington, *January 5, 1895.*

To the Philosophical Society of Washington:

The undersigned, a committee elected at the annual meeting of the Society, December 22, 1894, for the purpose of auditing the accounts of the Treasurer, respectfully report as follows:

We have examined the statement of receipts, including dues, interest, and sales, and find the same to be correct. We have examined the statements of disbursements, compared it with the vouchers, and find that they agree.

We have examined the returned checks and vouchers and find two vouchers unrepresented by checks, these checks being for $10 and $27.74 respectively. We have examined the bank book and find that the balance reported by it December 18, 1894, was $633.45, being $37.74 in excess of the balance reported by the Treasurer. The difference is accounted for by the two checks referred to, which had not been presented at the time the bank book was settled.

We have examined the United States and Cosmos Club bonds belonging to the Society and find them to be in amount and character as represented in the Treasurer's report, aggregating $5,500.

W J McGee, *Chairman.*
Isaac Winston.
Cleveland Abbe.

Mr. William Harkness read a paper on shade-glasses for telescopes in observing the sun. [Not published.]

Remarks were made upon this paper by Mr. Paul.

Mr. J. W. Powell presented a communication on The four methods of interpreting nature. [Not published.]

It was discussed by Messrs. Ward, Doolittle, and Bigelow.

430th Meeting. **January 19, 1895.**

Vice-President CLARKE in the chair.

Thirty-two members present.

Mr. G. K. GILBERT read a paper on The stratigraphic measurements of geologic time. [Published under the title Sedimentary measurement of Cretaceous time, in the Journal of Geology, 1895, vol. 3, pp. 121–127.]

It was discussed by Messrs. DUTTON, MCGEE, E. FARQUHAR, and WILLIS.

431st Meeting. **February 2, 1895.**

Vice-President CLARKE in the chair.

Thirty-five members and guests present.

Announcement was made of the death, on January 22, 1895, of Mr. S. V. BENÉT.

Mr. G. R. PUTNAM read a paper entitled Results of a transcontinental series of gravity measurements. [Published in this volume, pp. 31–60.]

This was supplemented by Mr. G. K. GILBERT with Geological notes concerning the same. [Published in this volume, pp. 61–75, and under the title, New light on isostasy, in Journal of Geology, 1895, vol. 3, pp. 331–334.]

The papers were discussed by Mr. PRESTON.

Mr. W. M. DAVIS read a communication on The need of reorganizing geography as a university study.

It was discussed by Messrs. ABBE, HARRINGTON, HARKNESS, WALCOTT, CLARKE, GOODFELLOW, H. FARQUHAR, and HAYDEN.

432d Meeting. **February 16, 1895.**

President DALL in the chair.

Thirty-seven members and guests present.

Announcement was made of the death, on February 3, 1895, of Mr. George E. Curtis.

The following biographical sketches were read:

Mr. James Clark Welling, written and read by Mr. J. Howard Gore. [Published in Bulletin of the Philosophical Society of Washington, vol. xii, pp. 486–496.]

Mr. Robert Stanton Avery, written and read by Mr. L. P. Shidy. [Published in Bulletin of the Philosophical Society of Washington, vol. xii, pp. 435–442.]

Mr. Garrick Mallery, written and read by Mr. Robert Fletcher. [Published in Bulletin of the Philosophical Society of Washington, vol. xii, pp. 466–471.]

Mr. Mark W. Harrington read a paper on The Central American rainfall. [Published in this volume, pp. 1–30.]

433d Meeting. **March 2, 1895.**

President Dall in the chair.

Thirty-two members and guests present.

Announcement was made of the death, on February 25, 1895, of Mr. William B. Taylor.

Mr. Wm. H. Dall read a paper on The discovery of marine fossils in the Pampean formation by Dr. H. von Ihering. [Published in Science, 1895, April 19, new series, vol. 1, no. 16, pp. 421–423.]

Mr. Alexander McAdie read a paper entitled New cloud classifications. [Published in this volume, pp. 77–86.]

It was discussed by Mr. Harrington.

Mr. Rogers Birnie read a paper on The army magazine rifle, caliber 30, model of 1892. [The facts presented in this paper were published in the Report of a Board of Officers convened to select magazine arms for the United States military service, in pamphlet form and as Appendix 9, Report of the Chief of Ordnance, U. S. Army, 1892.]

434th Meeting. **March 16, 1895.**

President DALL in the chair.

Thirty-two members and guests present.

Mr. G. K. GILBERT read a communication giving Additional notes on gravity determinations. [Published under the title Report on a geologic examination of some Coast and Geodetic Survey gravity stations, in U. S. Coast and Geodetic Survey Report for 1894, Appendix no. 1, pp. 51–55.]

It was discussed by Mr. HARKNESS.

Mr. CLEVELAND ABBE discussed the paper of Mr. McAdie, read at the last meeting.

Mr. F. W. CLARKE read a paper on The new gas in the atmosphere. [Not published.]

It was discussed by Messrs. BAKER, DOOLITTLE, KUMMELL, CHATARD, MCADIE, DALL, and WARD.

435th Meeting. **March 30, 1895.**

President DALL in the chair.

Twenty-four members present.

Announcement was made of the election to membership of ELLIOTT WOODS and LELAND PERRY SHIDY.

Mr. C. V. RILEY read a paper on Caprification. [Published under the title Some entomological problems bearing on California pomology and the caprification of the fig, in Proceedings of the American Pomological Society, 1895, 24th session, p. 113.]

It was discussed by Messrs. KUMMELL and ASHMEAD.

Mr. CHARLES H. KUMMELL read a paper on The logical necessity that if the attraction of gravitation depends on distance it must be in the inverse square.

It was discussed by Messrs. HALL, DOOLITTLE, WEAD, CHRISTIE, H. FARQUHAR, and GORE.

436th Meeting. **April 13, 1895.**

President Dall in the chair.

Thirty-four members present.

Mr. Simon Newcomb read a paper on The variation of latitude as affected by meteorological causes. [Published in the Astronomical Journal, vol. xvi, p. 81, and vol. xix, p. 158.]

It was discussed by Messrs. Bigelow, Dall, Abbe, H. Farquhar, Christie, Harkness, Kummell, and Gilbert.

Mr. Cyrus Adler read a paper on The cotton grotto, an ancient quarry in Jerusalem.

Mr. W J McGee read a paper on Certain influences of aridity on life. [Published in revised form under the title The beginning of agriculture, in the American Anthropologist, 1895, October, vol. viii, pp. 350–357.]

437th Meeting. **April 27, 1895.**

President Dall in the chair.

Thirty-one members and guests present.

Announcement was made of the death, on April 12, 1895, of Mr. W. L. Nicholson.

Mr. J. S. Billings read a communication on Municipal mortality statistics in the United States. [Not published.]

It was discussed by Messrs. Pawling, Tittmann, and Newcomb.

Mr. F. H. Bigelow read a paper on The earth, a magnetic shell. [Published in American Journal of Science, 1895, August, vol. 50, no. 296, pp. 81–99.]

It was discussed by Messrs. Christie and Dall.

438th Meeting. **May 11, 1895.**

President DALL in the chair.

Eighteen members present.

Announcement was made of the election to membership of JESSE PAWLING, JR.

Mr. ROGERS BIRNIE read a paper on Steel cylinders for gun-construction; stresses due to interior cooling. [Published in this volume, pp. 87–102.]

It was discussed by Mr. WEAD and the author.

Mr. ALEXANDER S. CHRISTIE read a communication on The latitude-variation tide. [Published in this volume, pp. 103–122.]

It was discussed by Messrs. MARTIN, PAUL, KUMMELL, and HAYFORD.

439th Meeting. **May 25, 1895.**

Vice-President CLARKE in the chair.

Twenty-five members and guests present.

Announcement was made of the election to membership of ADOLPH LINDENKOHL.

Mr. L. A. BAUER read a communication on The secular variation of terrestrial magnetism. [Published in American Journal of Science, 1895, August, vol. 50, no. 296, pp. 109–115; also September, pp. 189–204; and October, pp. 314–325.]

Mr. BAUER also read a paper entitled A preliminary analysis of the problem of terrestrial magnetism and its variations. [See reference above; also Science, vol. i, no. 25.]

These papers were discussed by Messrs. ABBE, HARRINGTON, CHRISTIE, and BAKER.

440th Meeting. **October 26, 1895.**

President Dall in the chair.

Twenty-four members and guests present.

Announcement was made of the death of General Orlando M. Poe, on October 2, 1895, and of Prof. C. V. Riley, on September 14, 1895.

Mr. Cleveland Abbe read a paper on Cloud formation and cloud nomenclature. [Not published.]

It was discussed by Mr. Littlehales and the author.

Mr. E. D. Preston read a paper, written by Mr. Adolph Lindenkohl, on Results of density observations made between 1874 and 1878 in the Gulf Stream and in the Gulf of Mexico. [Published in U. S. Coast and Geodetic Survey Report for 1895, Appendix no. 6. An abstract was published in Petermann's Mittheilungen, 1896, heft 2, and also in Science, 1896, February 21.]

It was illustrated by maps and discussed by Messrs. Abbe, Littlehales, Bigelow, Preston, Dall, and the author.

Mr. Frank H. Bigelow read a paper on Distribution of the sun spots on different meridians. [Published in U. S. Weather Bureau, Bulletin no. 21, chapter vi, 1898, pp. 140–146.]

It was discussed by Messrs. Powell, Paul, and the author.

441st Meeting. **November 9, 1895.**

President Dall in the chair.

Thirty members and guests present.

Mr. J. Howard Gore read a paper on International bibliography of mathematics.

It was discussed by Messrs. Martin, Mann, Abbe, Wead, and the author.

Mr. J. W. Powell read a paper on Matter. [For substance of this paper see a voluue by J. W. Powell entitled Truth and

Error, or the science of intellection. 12°, Chicago, Open Court Publishing Co., 1898.]

It was discussed by Messrs. Bigelow, Doolittle, W. B. Powell, Ward, Wead, and the author.

442d Meeting. **November 23, 1895.**

President Dall in the chair.

Twenty-six members and guests present.

Announcement was made that the General Committee had authorized the Secretary to furnish to "Science" from time to time abstracts of the proceedings of the Society, and that authors of papers desirous or willing to do so may prepare abstracts of their papers to be forwarded by the Secretary for publication in "Science."

Mr. F. M. Little read a communication on A mechanical method of reducing circular to linear harmonic motion.

Mr. J. Howard Gore read a communication on the Poor colonies of Holland.

It was discussed by Messrs. Dall and Bigelow.

Mr. H. A. Hazen read a paper on Aberrations of fog signals.

It was discussed by Messrs. Dall, Paul, Kummell, H. Farquhar, Wead, and the author.

443d Meeting. **December 6, 1895.**

By the courtesy of the authorities of Columbian University, the meeting was held in the lecture-room of that institution.

Mr. William H. Dall, President of the Society, delivered the annual address; subject, Alaska as it was and is, 1865–1895. [Published in this volume, pp. 123–162.]

444th Meeting. **December 21, 1895.**

TWENTY-FIFTH ANNUAL MEETING.

President DALL in the chair.

Twenty-four members present.

The minutes of the Twenty-fourth Annual Meeting were read and adopted.

The annual report of the Secretaries was read and accepted.

ANNUAL REPORT OF THE SECRETARIES FOR 1895.

WASHINGTON, D. C., *December 21, 1895.*

To the Philosophical Society of Washington:

The Secretaries have the honor to submit the following annual report for the year 1895:

The number of active members given in the last annual report was 155, of which number 6 have died, 5 have resigned, 4 have been dropped, and 4 transferred to the absent list. The total loss has thus amounted to 19 members, while but 4 new members have been elected during the year and 2 transferred from the absent to the active list, leaving a net loss to the Society of 13 members. The present active membership is therefore 142.

On the absent list there were 70 members at the beginning of the year, of whom 3 have died and 1 has resigned. This depletion and the balance of transfers above noted between the active and absent lists leaves at the present time a net total of 69 on the absent list.

The grand total of members, both active and absent, is therefore 211.

The active members who died were:

JOHN MILLS BROWNE.
DANIEL CURRIER CHAPMAN.
STEPHEN VINCENT BENÉT.
WILLIAM BOWER TAYLOR.
WALTER LAMB NICHOLSON.
CHARLES VALENTINE RILEY.

The new members elected are:

ELLIOTT WOODS.
JESSE PAWLING, JR.
LELAND PERRY SHIDY.
ADOLPH LINDENKOHL.

The General Committee has held 16 meetings in all—15 regular and 1 special—the average attendance at which was 11, the maximum being 22 and the minimum 8.

Sixteen meetings of the Society have been held, 14 of which were devoted to reading and discussion of papers, 1 to the President's annual address, and 1 to the annual reports and election of officers. The average attendance at the 14 meetings was 29.

Thirty-one separate papers were presented by 23 different members and 1 guest, and 3 biographies of deceased members, namely, James Clark Welling, Robert Stanton Avery, and Garrick Mallery, were read.

All meetings have been held in the Assembly Hall of the Cosmos Club, except that of December 6, which, being the occasion of the annual address of the President, William H. Dall, was held in the lecture-room of the Columbian University by the courtesy of the authorities.

On February 20 the organization of the Joint Commission of the Scientific Societies of this city, which was effected originally in 1888, was made more comprehensive by the adoption of a new constitution and the enlargement of the Commission to include the entire councils or governing bodies of the respective societies. Previously the Commission consisted of three delegates from each of the societies.

The original Commission represented five societies, namely, the Anthropological, Biological, Chemical, National Geographic, and Philosophical. The present Commission includes, in addition to these, the Entomological and Geological societies, making seven in all. A joint directory is published, and other arrangements are made from time to time of general interest and value in the form of joint meetings for special purposes and joint consideration of questions of common interest to the several societies.

On the 17th of April a meeting of the secretaries of these societies, called by the President of the Joint Commission, heard and considered favorably a request by Prof. J. McK. Cattell, editor of Science, that the secretaries should furnish from time to time, for publication in that journal, abstracts of the proceedings of the societies. This is being done by some, if not all, of the other societies, and recently the General Committee of this Society has authorized the Secretary to send to Science the titles of papers presented and names of the authors, and to forward

also such abstracts as the authors themselves may choose to prepare for that purpose.

It is apparent that the membership of the Society is slowly declining, being now but about 70 per cent of the maximum reached a few years ago. The average attendance at meetings was also less during the past year by 20 per cent than during the year 1894, and it is believed that these facts should receive the thoughtful consideration of the membership. In this connection, many members may be interested to read again the paper of Mr. G. K. Gilbert, presented November 26, 1887, and published in volume X of the Bulletin, analyzing the attendance and work of the Society from its organization in 1871 to that date, and alluding to the recent formation of special societies.

BERNARD R. GREEN,
W. C. WINLOCK,
Secretaries.

The annual report of the Treasurer was read and referred to an auditing committee consisting of Messrs. EASTMAN, ABBE, and WINSTON.

ANNUAL REPORT OF THE TREASURER FOR 1895.

DECEMBER 21, 1895.

To the Philosophical Society of Washington, D. C.:

The Treasurer has the honor to submit herewith a statement of the finances of the Society for the period beginning December 23, 1894, and ending December 21, 1895.

The income of the year 1895 was $830.76; the expenses properly chargeable to that year were $1,055.22, a difference of $224.46 against the Society on the year's transactions.

The investments of the Society amount to $5,500, the securities for which are on deposit in the Society's box at the office of the National Safe Deposit, Loan and Trust Company. A list of these securities, and of the furniture belonging to the Society, will be found at page 542 of volume XII of the Proceedings.

The assets of the Society are as follows:

The securities on deposit as above	$5,500 00
Cash balance at Riggs & Co., per statement herewith	516 25
Unpaid dues	131 00
Total	$6,147 25

The outstanding liabilities, if any, are trifling in amount.

Respectfully submitted.

WM. A. DE CAINDRY,
Treasurer.

The election of officers for the ensuing year was then held, with the following result:

President	F. W. CLARKE.	
Vice-Presidents	MARCUS BAKER. F. H. BIGELOW.	O. H. TITTMANN. L. F. WARD.
Treasurer	W. A. DE CAINDRY.	
Secretaries	B. R. GREEN.	W. C. WINLOCK.

MEMBERS AT LARGE OF THE GENERAL COMMITTEE.

CYRUS ADLER.
H. H. BATES.
ROGERS BIRNIE.
J. HOWARD GORE.
G. W. LITTLEHALES.
H. M. PAUL.
E. D. PRESTON.
J. STANLEY-BROWN.
C. D. WALCOTT.

445th Meeting. **January 4, 1896.**

Vice-President MARCUS BAKER in the chair.

Twenty-two members present.

Announcement was made of the standing committees for the year as follows:

Committee on Communications:

CYRUS ADLER, *Chairman.*
E. D. PRESTON. J. STANLEY-BROWN.

Committee on Publications:

MARCUS BAKER, *Chairman.*
W. A. DE CAINDRY. W. C. WINLOCK.

The Auditing Committee appointed at the last meeting submitted its report, which was accepted.

REPORT OF THE AUDITING COMMITTEE FOR 1895.

WASHINGTON, D. C., *January 3, 1896.*

To the Philosophical Society of Washington:

The undersigned, a committee elected at the annual meeting of the Society, December 21, 1895, for the purpose of auditing the accounts of the Treasurer, respectfully report as follows:

We have examined the statement of receipts, including dues, interest, and sales, and find the same to be correct.

We have examined the statement of disbursements, compared it with the vouchers, and find that they agree.

We have examined the returned checks (including the two checks, amounting to $37.74, referred to in the last auditing report) and vouchers and find that they agree.

We have examined the bank book and find that the balance reported by Riggs & Co. December 18, 1895, viz., $516.25, agrees with the Treasurer's report.

We have examined the United States and Cosmos Club bonds belonging to the Society and find them to be in amount and character as represented in the Treasurer's report, aggregating $5,500.

J. R. EASTMAN.
ISAAC WINSTON.

Lieut. W. H. BEEHLER, U. S. N., read a communication on The compensation of vibrations and other motions of a vessel at sea for the constant level base of the solarometer. [On this subject see a paper entitled The Solarometer, a modern navigating instrument, in Proceedings of the United States Naval Institute, vol. xxi, no. 1, whole no., 73.]

It was illustrated by diagrams and a solarometer. Discussed by Messrs. BIGELOW, BAKER, and the author.

Mr. E. D. PRESTON read a paper entitled Graphic reduction of star places. [Published in this volume, pp. 163–182.]

It was illustrated by diagrams and discussed by Messrs. BIGELOW, WINLOCK, BAKER, FARQUHAR, and the author.

446th Meeting. **January 18, 1896.**

Vice-President TITTMANN in the chair.

Forty members and guests present.

Mr. G. BROWN GOODE read a paper on The principles of museum administration. [Published in Annual Report of Museum Association, York (England), 1895, 73 pp.; also separately.]

It was discussed by Mr. BAKER and the author.

Mr. ISAAC WINSTON made a communication on The present form of precise leveling apparatus in use by the U. S. Coast and Geodetic Survey. [Not published.]

It was illustrated with instruments.

Mr. G. R. PUTNAM read a paper on Results of recent pendulum observations. [Published in American Journal of Science, 1896, March, vol. i, pp. 186–192; also separately.]

447th Meeting. **February 1, 1896.**

President CLARKE in the chair.

Thirty-two members and guests present.

Mr. LESTER F. WARD read a paper on The filiation of the sciences. [An abstract of this paper was published in Science, 1896, February 21, new series, vol. iii, no. 60, pp. 292–294.]

It was discussed by Messrs. J. W. POWELL and HENRY FARQUHAR.

448th Meeting. **February 15, 1896.**

President CLARKE in the chair.

Thirty-five members and guests present.

Announcement was made of the election to membership of RENÉ DE SAUSSURE.

Mr. W J McGee read a paper on An expedition to Seriland. [Published in Science, 1896, April 3, vol. iii, pp. 493–505.]

Mr. A. M. Ritchie described the Thermophone, showing the instrument.

Mr. W. H. Dall presented a communication on Some characteristics of the genus Spirula. [Published in Science, 1896, February 14, new series, vol. iii, no. 59, pp. 243–245.]

It was illustrated with diagrams and sketches.

Mr. J. H. Gore read a paper on The Groningen land-lease system.

449th Meeting. **February 29, 1896.**

President Clarke in the chair.

Twenty-five members and guests present.

Mr. Charles H. Kummell made a communication entitled A new solution of the geodetic problem. [An abstract of this paper was published in Science, 1896, March 20, new series, vol. iii, no. 64, p. 453.]

Mr. J. Walter Fewkes read a paper on The prehistoric culture of Tusayan. [Published in the American Anthropologist, 1896, May, vol. ix, pp. 151–173; also separately. An abstract was published in Science, 1896, March 20, new series, vol. iii, no. 64, pp. 452–453.]

It was discussed by Mr. Ward and the author.

450th Meeting. **March 14, 1896.**

President Clarke in the chair.

Twenty-seven members and guests present.

Announcement was made of the election to membership of James Robison Cook.

Mr. Carroll D. Wright read a paper on The factory system as an element in civilization. [Published in the Journal of Social Science, 1883, May, no. xvii.]

It was discussed by Messrs. Blount, Ward, Henry Farquhar, Gore, Wm. B. Powell, Wead, Hall, Clarke, and the author.

451st Meeting. **March 28, 1896.**

President Clarke in the chair.

Twenty-three members present.

Announcement was made of the death of Robert Edward Earll, on March 19, 1896, and of Thomas Lincoln Casey, on March 25, 1896.

Announcement was made of the election to membership of Mr. Immanuel Moses Casanowicz.

Mr. C. R. Dodge read a paper on Some undeveloped American fibers. [An abstract of this paper was published in Science, 1896, April 24, new series, vol. iii, no. 69, pp. 639–640.]

It was discussed by Messrs. Baker, Shidy, H. Farquhar, Bigelow, and the author.

Mr. Henry Gannett read a paper on Geographic names.

It was discussed by Messrs. H. Farquhar, Goode, Doolittle, Dodge, Baker, Clarke, Paul, Bigelow, Gilbert, and the author.

452d Meeting. **April 11, 1896.**

President Clarke in the chair.

Thirty-four members and guests present.

Mr. S. P. Langley made a communication entitled More recent observations on the infra-red spectrum. [An abstract of this paper was published in Science, 1896, April 24, new series, vol. iii, no. 69, pp. 640–641.]

Mr. R. A. Harris read a paper on The analysis and prediction of tides. [An abstract of this paper was published in Science, 1896, April 24, new series, vol. iii, no. 69, p. 641.]

Mr. E. D. Preston read a paper on French, German, and English systems of shorthand writing. [Not published.]

453d Meeting. **April 25, 1896.**

President Clarke in the chair.

Thirty-two members and guests present.

Mr. William Martin Aiken read a paper on The influence of climate upon architecture.

It was illustrated by photographs and maps and discussed by Messrs. Adler, Bigelow, Wead, and the author.

Mr. Glenn Brown read a paper on Early government architecture.

It was illustrated by photographs and discussed by Messrs. Clarke, Poindexter, and the author.

454th Meeting. **May 9, 1896.**

President Clarke in the chair.

Twenty-five members and guests present.

Announcement was made of the election to membership of George Miller Sternberg.

Mr. René de Saussure read a paper on The motion of solid bodies.

It was discussed by Mr. Kummell and the author.

Mr. J. Elfreth Watkins read a paper entitled A chapter in the early history of transportation in America.

455th Meeting. **May 23, 1896.**

President CLARKE in the chair.

Thirty-four members and guests present.

Announcement was made of the election to membership of Mr. HARRY FRANKLIN FLYNN.

The following biographical sketches were read:

THOMAS ANTISELL, by W. H. SEAMAN. [Published in this volume, pp. 367–370.]

STEPHEN VINCENT BENÉT, by ROGERS BIRNIE. [Published in this volume, pp. 370–374.]

J. MILLS BROWNE, by ROBERT FLETCHER.

THOMAS LINCOLN CASEY, by BERNARD R. GREEN. [Published in this volume, pp. 374–380.]

ROBERT EDWARD EARLL, by G. BROWN GOODE. [Published in this volume, pp. 388–390.]

WILLIAM LEE, by D. WEBSTER PRENTISS. [Published in this volume, pp. 405–407.]

WALTER LAMB NICHOLSON, by EDWARD GOODFELLOW. [Published in this volume, pp. 407–408.]

CHARLES VALENTINE RILEY, by L. O. HOWARD. [Published in this volume, pp. 412–416.]

WILLIAM BOWER TAYLOR, by W. J. RHEES. [Published in abridged form in this volume, pp. 418–426. Published in full in the Smithsonian Institution Annual Report for 1896, vol. i, p. 645.]

456th Meeting. **October 31, 1896.**

President CLARKE in the chair.

Twenty-five members and guests present.

Announcement was made of the election to membership of CHARLES RICHARDS DODGE.

Announcement was made of the deaths, on July 30, 1896, of Mr. J. M. TONER; on August 7, 1896, of Mr. SAMUEL SHELLA-

BARGER; on September 6, 1896, of Mr. G. BROWN GOODE; on September 20, 1896, of Mr. W. C. WINLOCK.

Mr. H. G. OGDEN read a biographical sketch of Mr. DANIEL CURRIER CHAPMAN. [Published in this volume, pp. 381–384.]

Mr. SIMON NEWCOMB presented a communication on the Bibliographical conference at London. [Not published.]

It was discussed by Messrs. BAKER, ADLER, DALL, STERNBERG, MANN, PAUL, and the author.

Mr. RENÉ DE SAUSSURE read a paper on A new trigonometry.

It was discussed by Messrs. BAKER, HARRIS, and KUMMELL.

457th Meeting. **November 14, 1896.**

President CLARKE in the chair.

Twenty-two members present.

Mr. C. D. WALCOTT presented a communication on A geologic reconnaissance in western Nevada and eastern California. [Published under the title The Post-Pleistocene elevation of the Inyo range and the lake beds of Waucobi embayment, Inyo county, California; in Journal of Geology, 1897, vol. 5, no. 4, pp. 340–348; also separately.]

It was illustrated by a map and diagrams.

Mr. T. W. STANTON read a paper, written by Mr. WM. H. DALL, on Recent advances in malacology. [Published in Science, 1896, November 27, new series, vol. iv, no. 100, pp. 770–773.]

Mr. J. HOWARD GORE read a paper on A Dutch experiment in socialism.

458th Meeting. **November 28, 1896.**

President CLARKE in the chair.

Twenty members present.

Mr. LESTER F. WARD read a paper on A reconnaissance through Indian Territory, Oklahoma, and southwestern Kan-

sas. [An abstract of this paper was published in Science, 1896, December 11, new series, vol. iv, no. 102, pp. 883–884.]

Mr. Walter Hough read a paper on The Hopi in relation to their plant environment. [Published in the American Anthropologist, 1897, February, vol. x, pp. 33–44; also separately.]

Mr. G. W. Littlehales gave an exhibition and description of a new machine for engraving parts of the plates from which charts and maps are printed. [Published in United States Letters Patent no. 561,677.]

This was discussed by Messrs. Clarke, Preston, Wead, Green, Hough, Harkness, and the author.

459th Meeting. December 12, 1896.

Vice-President Baker in the chair.

About one hundred and fifty members and guests present.

By the courtesy of the authorities this meeting was held in the Builders' Exchange, nos. 719–721 Thirteenth street.

Mr. Frank Wigglesworth Clarke, the retiring President, delivered the annual address on Chemistry in the United States. [Published in this volume, pp. 183–204.]

460th Meeting. December 26, 1896.

TWENTY-SIXTH ANNUAL MEETING.

President Clarke in the chair.

Twenty-three members present.

The minutes of the Twenty-fifth Annual Meeting were read and adopted.

The annual report of the Secretaries was read and accepted.

ANNUAL REPORT OF THE SECRETARIES FOR 1896.

WASHINGTON, D. C., *December 26, 1896.*

To the Philosophical Society of Washington:

The Secretaries have the honor to submit the following report for the year 1896:

The number of active members at the date of last report was 142. Of this number 6 have died, 6 have resigned, 10 have been transferred to the absent list, and 6 have been dropped for the non-payment of dues. Thus there has been a loss of 28. The membership has been increased by the election of 9 new members. The net loss in active membership is therefore 19, and the present active membership is 123.

The number of members on the absent list at date of last report was 69. This number was increased during the year by 10 transfers, making the total number on the absent list, so far as known, 79.

The total membership, both active and absent, is 202.

The list of deceased members is:

THOMAS LINCOLN CASEY.
ROBERT EDWARD EARLL.
GEORGE BROWN GOODE.
SAMUEL SHELLABARGER.
JOSEPH MEREDITH TONER.
WILLIAM CRAWFORD WINLOCK.

The list of new members is:

IMMANUEL MOSES CASANOWICZ.
JAMES ROBISON COOK.
CHARLES RICHARDS DODGE.
HARRY FRANKLIN FLYNN.
WALTER HOUGH.
WILLIAM FOWKE RAVENEL PHILLIPS.
RENÉ DE SAUSSURE.
GEORGE MILLER STERNBERG.
DAVID WATSON TAYLOR.

The following members were transferred to the absent list:

TARLETON HOFFMAN BEAN.
OLIVER LANARD FASSIG.
LINCOLN GRANT EAKINS.
JOHN FILLMORE HAYFORD.
MARK WALDO HARRINGTON.
JOSEPH PAXSON IDDINGS.
WILLIAM HENRY HOLMES.
JEFFERSON FRANKLIN MOSER.
ALEXANDER MCADIE.
JESSE PAWLING, JR.

The following is the list of resignations:

Henry Hobart Bates.	Alexander Smyth Christie.
Frederic Perkins Dewey.	Joseph Silas Diller.
John Henry McCormick.	Robert Simpson Woodward.

The General Committee held 16 meetings; average attendance, 10; maximum, 14; minimum, 7.

The Society held 16 meetings, 14 of which were devoted to the reading and discussion of papers, one to the President's annual address, and one to the annual meeting for reports and election of officers. The average attendance at the 14 meetings was 28, one less than last year.

Thirty-one papers were presented by 20 members and 6 guests. Ten biographical notices of deceased members were read, as follows:

Thomas Antisell.	Stephen Vincent Benét.
John Mills Browne.	Thomas Lincoln Casey.
Daniel Currier Chapman.	Robert Edward Earll.
William Lee.	Walter Lamb Nicholson.
Charles Valentine Riley.	William Bower Taylor.

All meetings were held in the Assembly Hall of the Cosmos Club except that of December 12, which, being the occasion of the annual address of the President, was held at the Builders' Exchange, No. 719–721 Thirteenth street.

Two papers were published during the year, viz., Alaska as it was and is 1865–1895, the presidential address delivered by Mr. W. H. Dall; and, Graphic reduction of star places, by Mr. E. D. Preston.

On January 18, 1896, Mr. Rogers Birnie was elected Treasurer in place of Mr. W. A. De Caindry, resigned.

On October 31, 1896, Mr. J. Elfreth Watkins was elected Secretary in place of Mr. W. C. Winlock, who died September 20.

Bernard R. Green,
J. Elfreth Watkins,
Secretaries.

The annual report of the Treasurer was read and referred to an auditing committee consisting of Messrs. Henry Farquhar, C. K. Wead, and Walter Hough.

ANNUAL REPORT OF THE TREASURER FOR 1896.

WASHINGTON, D. C., *December 26, 1896.*

To the Philosophical Society of Washington, D. C.:

This report of the finances of the Society covers the yearly period from December 21, 1895, to December 26, 1896.

The funds and property of the Society for which the Treasurer is accountable, including the balance of $516.25, per last annual report, were received from Mr. Wm. A. De Caindry on January 21, 1896.

The income of the year 1896 is $797.35, the expenses properly chargeable to the year are $479.08, leaving a surplus of $318.27 on the year's transactions.

On January 21, 1896, three Cosmos Club 5.20 bonds of 1886 (Nos. 17, 132, and 153), were relinquished, having been peremptorily redeemed by the Cosmos Club as determined by drawing by lot. The investments of the funds of the Society now amount to $5,200, in securities, which are deposited in the Society's box at the office of the National Safe Deposit, Loan and Trust Company, as follows:

Two U. S. 4 per cent. bonds, No. 64,596, for $500, and No. 135,639, for $1,000.

Thirty-seven Cosmos Club 5.20 bonds, 1886, $100 each, Nos. 16, 18, 19, 20, 21, 22, 45, 70, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 135, 136, 155, 156, 159, 161, 162, 163, 164, 165, 166, 167, 185, 193, 194, 195.

The assets of the Society are:

The securities deposited as stated	$5,200 00
Cash balance at the Riggs National Bank, per statement herewith	1,230 38
Unpaid dues	120 00
Total	$6,550 38

There are no outstanding liabilities to report.

Respectfully submitted.

R. BIRNIE,
Treasurer.

The election of officers for the ensuing year resulted as follows:

President	MARCUS BAKER.	
Vice-Presidents	F. H. BIGELOW. O. H. TITTMANN.	L. F. WARD. C. D. WALCOTT.
Treasurer	ROGERS BIRNIE.	
Secretaries	J. ELFRETH WATKINS.	B. R. GREEN.

MEMBERS AT LARGE OF THE GENERAL COMMITTEE.

CYRUS ADLER. H. M. PAUL.
WILLIAM A. DE CAINDRY. E. D. PRESTON.
J. HOWARD GORE. G. M. STERNBERG.
G. W. LITTLEHALES. F. W. TRUE.
RICHARD RATHBUN.

461st Meeting. **January 9, 1897.**

President BAKER in the chair.

Thirty-five members and guests present.

Announcement was made of the standing committees as follows:

Committee on Communications:

CYRUS ADLER. G. K. GILBERT. E. D. PRESTON.

Committee on Publications:

H. M. PAUL. F. H. NEWELL. G. W. LITTLEHALES.

The report of the Auditing Committee appointed at the last meeting was read and accepted.

REPORT OF THE AUDITING COMMITTEE FOR 1896.

WASHINGTON, *January 5, 1897.*

To the Philosophical Society of Washington:

The undersigned, a committee selected at the annual meeting of the Society, December 26, 1896, to audit the accounts of the Treasurer, respectfully report as follows:

We have examined the vouchers of expenses of Mr. R. Birnie, Treasurer, and find them correct.

We have examined his statement of receipts from dues of members, interest on bonds, and sales of publications and find said receipts to be in accordance with said statement.

We have examined the United States and Cosmos Club bonds belonging to the Society and find them to be in amount and character as reported by the Treasurer, aggregating $5,200.

HENRY FARQUHAR.
WALTER HOUGH.

Mr. J. R. EASTMAN read a biographical sketch of Mr. WILLIAM CRAWFORD WINLOCK. [Published in this volume, pp. 431–434.]

Mr. AINSWORTH R. SPOFFORD read a biographical sketch of Mr. J. M. TONER. [Published in this volume, pp. 426–430.]

Mr. L. A. BAUER read a paper entitled Earth-air electric currents. [Published in Terrestrial Magnetism. 8°, Cincinnati, 1897, March, vol. ii, pp. 11–22.]

It was discussed by Messrs. BIGELOW, LITTLEHALES, BAKER, and the author.

462d Meeting. **January 23, 1897.**

Vice-President BIGELOW in the chair.

Seventeen members and guests present.

Announcement was made of the election to membership of PHILIP ROUNSEVILLE ALGER and JAMES PAGE.

Mr. FRANK H. BIGELOW read a paper on The problem of international cloud observations. [Not published.]

It was discussed by Mr. ABBE and the author.

Mr. C. H. KUMMELL read a paper on A binomial theorem expressed in the form of a factorial which is always convergent.

It was discussed by Mr. GORE and the author.

463d Meeting. **February 6, 1897.**

President Baker in the chair.

Forty-three members and guests present.

Mr. Cyrus Adler presented a communication on The Jewish calendar.

It was discussed by Messrs. Newcomb, Baker, and the author.

Mr. J. R. Eastman read a paper on The relations of science and the scientific citizen to the general government. [Published in Science, 1897, April 2, new series, vol. v, no. 118, pp. 525–531.]

Mr. Marcus Baker made a communication on The Philosophical Society. [Not published.]

These papers were discussed by Messrs. Walcott, Gore, Sternberg, Eastman, Dall, Ward, Adler, and Bigelow.

464th Meeting. **February 20, 1897.**

Vice-President Bigelow in the chair.

Twenty-seven members and guests present.

Mr. E. D. Preston read a paper on The transcontinental arc from Cape May to San Francisco. [Published in this volume, pp. 205–222.]

It was discussed by Messrs. Green, Kummell, Bigelow, and the author.

Mr. William Eimbeck read a paper on The new primary base apparatus of the U. S. Coast and Geodetic Survey. [Published in Coast and Geodetic Survey Report for 1897, Appendices 11 and 12, pp. 737–774.]

It was illustrated by an exhibition of a five-meter bar, and discussed by Messrs. Preston, Tittmann, Birnie, Bigelow, Kummell, and the author.

Mr. Charles Richards Dodge read a paper on The systematic classification of textile and other useful fibers of the world,

Mr. J. Howard Gore read a paper on A Dutch practical charity.

It was discussed by Messrs. Bigelow, G. L. Burr, and the author.

465th Meeting. **March 6, 1897.**

President Baker in the chair.

Seventeen members present.

Mr. J. W. Powell read a paper on Principles of classification. [For the substance of this paper see "On Regimentation," Fifteenth Annual Report of the Bureau of Ethnology, pp. civ–cxxi, Washington, 1897.]

It was discussed by Messrs. Ward, Baker, and the author.

Mr. J. Elfreth Watkins read a paper on A forgotten experiment of Franklin's.

Mr. Baker read a paper on The boundary of the District of Columbia. [Published in the Records of the Columbia Historical Society, 1897, vol. i, pp. 215–224.]

466th Meeting. **March 20, 1897.**

President Baker in the chair.

Eighty-two members and guests present.

Mr. S. P. Langley made a communication on Mechanical flight. [For the substance of this paper see McClure's Magazine, 1897, June.]

This was discussed by Messrs. Paul, Gilbert, Hazen, and Spofford.

Mr. George M. Sternberg made a communication on Toxins and anti-toxins. [Not published.]

It was discussed by Messrs. Kummell, Gordon, Mann, and the author.

Mr. C. K. Wead read a paper on Mediæval church organs. [Published in full in Music, Chicago, February, 1897; also in Proceedings of the American Association for the Advancement of Science, 1899, pp. 96–102.]

467th Meeting. **April 3, 1897.**

President Baker in the chair.

Eighteen members and guests present.

Announcement was made of the election to membership of Mr. Paul Brockett and Mr. L. Eugene Emerson.

Announcement was made of the arrangement between this Society and the Chemical Society of Washington, in accordance with which members of either Society may, upon giving notice to the Secretary of the other, receive the regular notices of its meetings, and be welcome to attend them.

Mr. Gilbert Thompson read a paper on The Washington monument as a sun dial. [Not published.]

It was illustrated by diagrams and discussed by Messrs. Baker and Kummell.

Mr. Charles H. Kummell presented a communication entitled Discussion of merit contests in college examinations by the method of least squares.

It was discussed by Messrs. Bigelow, Gore, Baker, and the author.

468th Meeting. **April 17, 1897.**

President Baker in the chair.

Fifty-one members and guests present.

Announcement was made of the election to membership of Mr. Frederick Haynes Newell.

Mr. B. E. Fernow read a paper on The policy of forest reservations. [The substance of this paper was published in a separate pamphlet by the American Forestry Association in 1895.]

It was discussed by Messrs. Tittmann, Walcott, Abbe, and Steele.

Mr. C. F. Marvin read a paper on Recent progress in the development of the kite. [Published, under the title The mechanics and equilibrium of kites, in Monthly Weather Review, 4°, Washington, 1897, April, vol. xxv, pp. 136–161; also separately as "W. B. no. 122," entitled A monograph on the mechanics and equilibrium of kites.]

It was illustrated by models.

Mr. H. A. Hazen read a paper on The evolution of a soaring kite.

It was illustrated by lantern slides.

469th Meeting. **May 1, 1897.**

President Baker in the chair.

Twenty-one members present.

The two papers on The evolution of the kite, presented at the last meeting, were discussed by Messrs. Marvin, Bigelow, Langley, Paul, and Hazen.

Mr. C. K. Wead read a communication on A system of genealogical notation. [Not published.]

It was discussed by Messrs. Paul, Hazen, and Mann.

Mr. Cyrus Adler spoke on the subject of A proposed catalogue of Egyptian papyri and royal monuments.

This was discussed by Mr. Hough.

470th Meeting. **May 15, 1897.**

President Baker in the chair.

Eleven members present.

Announcement was made of the death, on April 17, 1897, of Mr. Charles Hugo Kummell.

Mr. F. H. Bigelow read a paper on The earth's magnetic field. [Published in U. S. Weather Bureau Bulletin no. 21 (W. B. no. 150), 1898, chap. iv, pp. 81–93.]

It was discussed by Messrs. Baker and Wead.

471st Meeting. May 29, 1897.

President Baker in the chair.

Twenty-eight members and guests present.

Mr. J. S. Diller read an obituary notice, prepared by himself and Mr. O. L. Fassig, of Mr. George E. Curtis. [Published in this volume, pp. 384–387.]

Mr. W J McGee read a paper on Some relations between man and lower animals. [Published under the title Beginning of zoöculture; in the American Anthropologist, 1897, July, vol. x, pp. 215–230.]

Mr. Baker made a communication on The Venezuelan Boundary Commission and its work. [Published in the National Geographic Magazine, July-August, 1897, vol. viii, pp. 193–201.]

It was illustrated by maps.

472d Meeting. October 16, 1897.

President Baker in the chair.

Seventeen members present.

Announcement was made of the election to membership of Mr. Charles Colt Yates.

Mr. G. W. Littlehales read a paper on Secular change in the direction of the terrestrial magnetic field at the earth's surface. [Published in this volume, pp. 269–336.]

It was discussed by Messrs. Bigelow, Gilbert, and Tittmann.

Mr. H. A. Hazen read a paper entitled Is the water-level of Lake Michigan gradually diminishing?

It was discussed by Messrs. Gilbert and Birnie.

473d Meeting. **October 30, 1897.**

President BAKER in the chair.

Thirty-four members present.

Announcement was made of the death, on October 18, 1897, of Mr. NEWTON LEMUEL BATES.

Mr. R. T. HILL read a paper on Geographic changes in tropical America in late geologic time. [Published in Bulletin of the Museum of Comparative Zoölogy at Harvard College, Cambridge, 1899, September, vol. xxxiv (geological series, vol. iv), pp. 198–224.]

It was illustrated by maps and diagrams and discussed by Mr. BAILEY WILLIS.

Mr. McGEE opened a discussion on the Two Associations for the Advancement of Science, viz., the American and the British. The discussion was continued by Messrs. HARKNESS, GILL, DALL, BIGELOW, and WILEY.

474th Meeting. **November 13, 1897.**

President BAKER in the chair.

Seventeen members present.

Mr. BIGELOW read a communication on The probable state of the sky along the eclipse track of May 28, 1900. [Published in Monthly Weather Review, 4°, Washington, 1897, September, vol. xxv, pp. 394–395; also separately by the Weather Bureau as "W. B. no. 142."]

It was discussed by Messrs. ABBE, BIGELOW, BIRNIE, and BAKER.

Mr. J. HOWARD GORE read a paper on the Antwerp nations—profit-sharing labor organizations.

It was discussed by Messrs. WATKINS, BLOUNT, WEAD, BAKER, and the author.

Mr. BAKER presented some notes on The origin of the dollar symbol. [An abstract of this communication was published in the Independent, 1899, March 16, vol. li, pp. 756–757.]

It was discussed by Messrs. MARTIN, BLOUNT, H. FARQUHAR, BIRNIE, GORE, and the author.

475th Meeting. **November 27, 1897**

President BAKER in the chair.

Twenty-eight members present.

Announcement was made of the election to membership of HERBERT FRIEDENWALD.

Mr. GEORGE M. STERNBERG read a paper on The Twelfth International Medical Congress. [Not published.]

Mr. O. H. TITTMANN read a paper on A year's work of the International Bureau of Weights and Measures.

It 'was discussed by Messrs. HARKNESS, WEAD, EIMBECK, HENRY FARQUHAR, and BAKER.

Mr. GEORGE P. MERRILL read a paper on The Seventh International Congress of Geologists. [Not published.]

It was illustrated by maps and photographs.

476th Meeting. **December 11, 1897.**

TWENTY-SEVENTH ANNUAL MEETING.

President BAKER in the chair.

Twenty-six members present.

Announcement was made of the election to membership of Mr. GEORGE COLTON MAYNARD.

The minutes of the Twenty-sixth Annual Meeting were read and adopted.

The report of the Secretaries was read and accepted. The following is the

ANNUAL REPORT OF THE SECRETARIES FOR 1897.

WASHINGTON, D. C., *December 11, 1897.*

To the Philosophical Society of Washington:

GENTLEMEN: Your Secretaries have the honor to submit the following report for the year 1897:

The number of active members at the date of the last annual report was 123. Of this number 2 have died, 4 have resigned, 2 have been transferred to the absent list, and 4 have been dropped for non-payment of dues. There has thus been a loss of 12 members. The membership has been increased by the election of 8 new members and by the transfer of 2 from the absent to the active list. There has thus been a net loss of 2, and the present active membership is 121.

The number of members on the absent list at date of last report was 79. This number was decreased by 2 transfers to the active list and increased by 2 transfers from the active list, leaving the number on the absent list the same as at date of last report, viz., 79.

The following is the list of new members:

PHILIP ROUNSEVILLE ALGER. PAUL BROCKETT.
L—— EUGENE EMERSON. HERBERT FRIEDENWALD.
GEORGE COLTON MAYNARD. FREDERICK HAYNES NEWELL.
JAMES PAGE. CHARLES COLT YATES.

The active members who died during the year are:

NEWTON LEMUEL BATES. CHARLES HUGO KUMMELL.

The transfers from the absent to the active list are:

WILLIAM HENRY HOLMES. HENRY SMITH PRITCHETT.

And from the active to the absent list:

ASAPH HALL. CHARLES RICHARD VAN HISE.

The resignations are:

PHILIP ROUNSEVILLE ALGER. STIMSON JOSEPH BROWN.
MYRICK HASCALL DOOLITTLE. JOHN SHERMAN.

The General Committee held 15 meetings; average attendance, 10.

The Society held 16 meetings, of which 15 were for the reading and discussion of papers and one was the annual meeting for reports and election of officers. The average attendance was 29. Thirty-five papers were read by 24 members. Also biographical notices were read of—

GEORGE EDWARD CURTIS. JOSEPH MEREDITH TONER.
WILLIAM CRAWFORD WINLOCK.

All meetings were held in the Assembly Hall of the Cosmos Club, 1518 H street.

Two papers were published during the year, viz., Chemistry in the United States, by F. W. Clarke; The transcontinental arc, by E. D. Preston.

BERNARD R. GREEN,
J. ELFRETH WATKINS,
Secretaries.

The report of the Treasurer was read and referred to an auditing committee, consisting of Messrs. McGEE, WINSTON, and MARTIN. The following is the

ANNUAL REPORT OF THE TREASURER FOR 1897.

WASHINGTON, D. C., *December 11, 1897.*

To the Philosophical Society of Washington, D. C.:

This report covers the yearly period from December 26, 1896, to December 11, 1897.

The income and expenses of the year 1897, aside from the redemption, sale, and purchase of bonds, are as follows: Income, \$826.46; expenses, \$284.61, leaving a surplus of \$542.05 on ordinary transactions for the year.

On February 6, 1897, acting upon a report of the same date, submitted by a subcommittee composed of Messrs. Baker, Eastman, and Birnie, that had been appointed to consider the matter of investment of funds of the Society, the General Committee directed the Treasurer to purchase one \$1,000 6 per cent. bond of the Columbia Street Railway Company, and at the same time

authorized him to exchange Cosmos Club bonds of the first issue on hand for those of the second and third issues, so as to retain, if practicable, the same amount of investment in these bonds as then held, inasmuch as the bonds of the first issue are now being redeemed by the Club. Several exchanges of these bonds have been effected through the kind coöperation of Mr. Wm. A. De Caindry, treasurer of the Cosmos Club.

The transactions in bonds during the year are as follows:

Redeemed one $100 Cosmos Club 5 per cent. bond of 1886; sold two $100 Cosmos Club 5 per cent. bonds of 1886; purchased two $100 Cosmos Club 5 per cent. bonds of 1891; purchased one $1,000 Columbia Street Railway 6 per cent. bond; exchanged five $100 Cosmos Club 5 per cent. bonds of 1886 for five of 1893, making a net increase of $900, face value, in the bond investments of the Society. These investments now amount to $6,100 in securities, which are deposited in the Society's box with the National Safe Deposit, Loan and Trust Company, as follows:

Two U. S. 4 per cent. registered bonds, No. 64,596, for $500, and No. 135,639, for $1,000; twenty-nine Cosmos Club 5 per cent. bonds of 1886 for $100 each, Nos. 70, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 135, 136, 155, 156, 159, 161, 162, 163, 164, 165, 166, 167, 185, 193, 194, 195; two Cosmos Club 5 per cent. bonds of 1891 for $100 each, Nos. 217 and 245; five Cosmos Club 5 per cent. bonds of 1893 for $100 each, Nos. 1, 53, 56, 57, and 81; one Columbia Street Railway 6 per cent. bond, No. 299, for $1,000.

The present assets of the Society are:

The securities, deposited as stated, face value	$6,100 00
Cash balance with the Riggs National Bank, as per statement appended	712 42
Unpaid dues	110 00
Total	$6,922 42

There are no outstanding liabilities to report.

Respectfully submitted.

R. Birnie,
Treasurer.

The election of officers for the ensuing year was then held, with the following result:

President	F. H. Bigelow.	
Vice-Presidents	G. M. Sternberg. O. H. Tittmann.	C. D. Walcott. L. F. Ward.
Treasurer	Rogers Birnie.	
Secretaries	J. Elfreth Watkins.	E. D. Preston.

MEMBERS AT LARGE OF THE GENERAL COMMITTEE.

Cyrus Adler. G. W. Littlehales.
W. A. De Caindry. H. M. Paul.
J. H. Gore. H. S. Pritchett.
Bernard R. Green. Richard Rathbun.
F. W. True.

477th Meeting. **January 8, 1898.**

President Bigelow in the chair.

Twenty-nine members present.

Announcement was made of the standing committees for the year as follows:

Committee on Communications:

J. H. Gore. H. S. Pritchett. F. W. True.

Committee on Publications:

Marcus Baker. J. Elfreth Watkins. Cyrus Adler.

The report of the Auditing Committee appointed at the last meeting was submitted and accepted.

REPORT OF THE AUDITING COMMITTEE FOR 1897.

Washington, D. C., *December 16, 1897.*

To the Philosophical Society of Washington:

The undersigned, a committee appointed at the annual meeting of the Society, December 11, 1897, for the purpose of

auditing the accounts of the Treasurer, respectfully report as follows:

We have examined the statement of receipts, including dues, interest, and sales, and find the same to be correct.

We have examined the statement of disbursements, compared it with the vouchers, and find that they agree.

We have examined the returned checks and vouchers and find one voucher unrepresented by a check, this check being for $0.30.

We have examined the bank book and find that the balance on deposit reported by Riggs & Co. December 11, 1897, viz., $712.72, agrees with the Treasurer's report if the outstanding check for $0.30, above mentioned, is deducted.

We have examined the United States and Cosmos Club bonds and the bond of the Columbia Street Railway Company and find them to be in amount and character as represented in the Treasurer's report, aggregating $6,100.

Isaac Winston.
Artemas Martin.

Mr. J. E. Watkins read a paper on The transportation and lifting of heavy bodies by the ancient engineers—a possible method. [Published in Cassier's Magazine, New York, 1898, December, vol. xv, no. 2, pp. 108–114; republished, with additions, in Smithsonian Institution Annual Report for 1898.]

It was discussed by Messrs. Adler, Bigelow, Dall, Wead, and the author.

Mr. T. J. J. See read a paper on Recent discoveries of double stars in the Southern hemisphere.

It was discussed by the President and by Messrs. Hedrick, Abbe, Walcott, and the author.

Mr. C. D. Walcott read a paper on The United States forestry reserves. [Published in Popular Science Monthly, 1898, February, pp. 1–13; also separately.]

It was discussed by Mr. Birnie and the author.

478th Meeting. **January 22, 1898.**

President BIGELOW in the chair.

Twelve members present.

Mr. WALTER HOUGH read a paper on The origin and range of the Eskimo lamp. [Published in the American Anthropologist, 1898, April, vol. xi, pp. 116–122; also separately.]

It was discussed by Messrs. DALL, WATKINS, the President, and the author.

Mr. J. H. GORE read a paper on Gheel, a colony of the insane.

It was discussed by Mr. BELL, the President, and the author.

479th Meeting. **February 5, 1898.**

President BIGELOW in the chair.

Twenty-six members present.

Mr. H. W. WILEY addressed the Society on the subject of Useful bacteria. [Not published.]

It was discussed by Messrs. STERNBERG, BIGELOW, and SHIDY.

Mr. GEORGE M. STERNBERG read a paper on Pathogenic bacteria. [Not published.]

It was discussed by Messrs. BIGELOW, TRUE, and the author.

Mr. E. A. DE SCHWEINITZ read a paper on Toxins and antitoxins. [Published as Bulletin no. 23, Bureau of Animal Industry, Department of Agriculture, 1898 and 1899; also in Annual Report of Bureau of Animal Industry for 1898.]

It was discussed by Messrs. BIGELOW, STERNBERG, and the author.

480th Meeting. **February 19, 1898.**

President BIGELOW in the chair.

Eighteen members present.

Mr. H. A. Hazen read a paper on Weather folk-lore, its origin and value.

It was discussed by Messrs. Bigelow, Sternberg, Dall, Green, and the author.

Mr. W. H. Dall read a paper on The condition of Tertiary paleontology in the United States. [Not published.]

481st Meeting. **March 5, 1898.**

President Bigelow in the chair.

Nineteen members present.

The Secretary read a paper prepared by Mr. A. Lindenkohl on The specific gravity of the waters of the northeast Pacific ocean. [Published in U. S. Coast and Geodetic Survey Report for 1898, Appendix no. 10; also in Petermann's Mittheilungen, 1897, heft xii; also in Science, 1898, December 30, new series, vol. viii, no. 209, pp. 941–944.]

It was discussed by Messrs. Dall, Preston, Littlehales, and the author.

Mr. F. H. Bigelow read a paper on The results of balloon ascensions in determining the temperature of the air. [Published in International Cloud Report, 1899, p. 750.]

It was discussed by Messrs. Hazen, Tittmann, Dall, and the author.

482d Meeting. **March 19, 1898.**

President Bigelow in the chair.

Twenty-six members present.

Announcement was made of the election to membership of William Candler Hodgkins.

Mr. H. Friedenwald read a paper on The Declaration of Independence: A summary of colonial grievances. [Not published.]

Mr. BIGELOW read a paper on The state of the Philosophical Society. [Not published.]

It was discussed by Messrs. MANN, GORE, CLARKE, WEAD, FARQUHAR, DALL, EASTMAN, BAKER, ADLER, and the author.

483d Meeting. **April 2, 1898.**

The address of the retiring President, Mr. MARCUS BAKER, on A century of geography in the United States, was delivered at the Cosmos Club. [Published in this volume, pp. 223–240; also in Science, 1898, April 22, new series, vol. vii, no. 173, pp. 541–551.]

484th Meeting. **April 16, 1898.**

President BIGELOW in the chair.

Twenty-two members present.

Mr. C. C. YATES read a paper on Personal equation in estimating tenths. [For brief abstract of this paper see Science, 1898, May 6, new series, vol. vii, no. 175, p. 647.]

It was discussed by Messrs. PAUL, PRESTON, BAKER, BIGELOW, GORE, and the author.

Mr. G. W. LITTLEHALES read a paper on The progress in trans-oceanic navigation in the eighteenth and nineteenth centuries. [For brief abstract of this paper see Science, 1898, May 6, new series, vol. vii, no. 175, p. 647.]

Mr. SIGNE RINK read a paper on The origin of the Eskimo name for the white man.

It was discussed by Messrs. DALL and BIGELOW.

485th Meeting. **April 30, 1898.**

President BIGELOW in the chair.

Twenty-three members present.

Mr. William Eimbeck read a paper on Terrestrial refraction. [To be published in Coast and Geodetic Survey Report for 1899.]

It was discussed by Messrs. Pritchett, Bigelow, Preston, Wead, and the author.

Mr. E. D. Preston read a paper on Recent progress in geodesy. [Published in this volume, pp. 251–268.]

It was discussed by Messrs. Gore, Bigelow, Wilczynski, and Pritchett.

486th Meeting. **May 14, 1898.**

President Bigelow in the chair.

Twenty-four members present.

This evening was devoted to a discussion of plans for the work of the Society.

487th Meeting. **May 28, 1898**

President Bigelow in the chair.

Fourteen members present.

Mr. Baker read a biographical notice of Charles Hugo Kummell. [Published in this volume, pp. 404–405.]

Mr. Tittmann read a biographical notice of Orlando M. Poe. [Published in this volume, pp. 409–412.]

Mr. L. A. Fischer read a paper on The comparison of line and end standards. [Published in this volume, pp. 241–250; also an abstract in Science, 1898, June 17, new series, vol. vii, no. 181, pp. 839–840.]

It was discussed by Mr. Hayford.

Mr. A. Lindenkohl read a paper on The submerged terminal moraines of the southern coast of New England. [An abstract of this paper was published in Science, 1898, June 17, new series, vol. vii, no. 181, p. 840.]

It was discussed by Messrs. Dall and Bigelow.

488th Meeting. October 29, 1898.

President BIGELOW in the chair.

Twenty-three members present.

Mr. CLEVELAND ABBE read a communication on Weather, climate, and crops. [Not published.]

It was discussed by Messrs. BAKER, PAUL, BIGELOW, DOOLITTLE, and GORE.

Mr. ROLLIN A. HARRIS read a communication on Particular solutions of certain partial differential equations occurring in mathematical physics.

It was discussed by Messrs. BIGELOW, ABBE, and GORE.

489th Meeting. November 12, 1898.

President BIGELOW in the chair.

Twenty-two members present.

Mr. E. GOODFELLOW read a paper on The Philippines.

It was discussed by Messrs. ABBE, BIGELOW, DALL, GORE, PROCTOR, and OGDEN.

490th Meeting. November 26, 1898.

President BIGELOW in the chair.

Twenty-six members and guests present.

Mr. E. D. PRESTON read a paper on The International Geodetic Association meeting at Stuttgart, October 3–12, 1898. [Published in Science, 1898, December 16, new series, vol. viii, no. 207, pp. 841–847.]

It was discussed by Messrs. BIGELOW, PRITCHETT, and GORE.

Mr. CYRUS ADLER read a paper on The International Catalogue of Scientific Literature.

It was discussed by Messrs. BIGELOW, PAUL, DALL, and WEAD.

Mr. René de Saussure read a paper on Graphical determinations of stream lines.

It was discussed by Mr. Bigelow.

491st Meeting. **December 10, 1898.**

President Bigelow in the chair.

Thirty members and guests present.

Messrs. Wead and Goodfellow were appointed an auditing committee.

Mr. Adler made an informal communication on The forging of antiquities.

Mr. René de Saussure read a paper on Graphic determinations of stream lines in vortex motion.

It was discussed by Messrs. Bigelow, Gore, and the author.

Mr. W. H. Dall read a paper on The proposed University of the United States. [Published in the American Naturalist, 1899, February, vol. xxxiii, no. 386, pp. 97–107.]

It was discussed by Messrs. Sternberg, Ward, Adler, Abbe, and Gore.

Mr. Bigelow read a paper on Two remarkable semi-diurnal periods. [Published in International Cloud Report, 1899, p. 474.]

492d Meeting. **December 22, 1898.**

TWENTY-EIGHTH ANNUAL MEETING.

President Bigelow in the chair.

Fourteen members present.

The minutes of the Twenty-seventh Annual Meeting were read and adopted.

The annual report of the Secretaries was read and accepted.

ANNUAL REPORT OF THE SECRETARIES FOR 1898.

WASHINGTON, D. C., *December 22, 1898.*

To the Philosophical Society of Washington:

The Secretaries have the honor to submit the following annual report for the year 1898:

The number of active members at date of last annual report was 121. Of this number 6 have resigned, and 1 was dropped for non-payment of dues. Thus there has been a loss of 7. The membership has been increased by the election of 4 new members. The net loss is 3, and the present active membership is 118.

The number of members on the absent list at date of last report was 79. So far as known this number remains unchanged.

No deaths have occurred among the active members.

The new members are:

LYMAN JAMES BRIGGS.	WILLIAM CANDLER HODGKINS.
FRANK MILTON LITTLE.	FRANK GUSTAV RADELFINGER.

The members who resigned are:

EDWARD FARQUHAR.	BERNHARD EDUARD FERNOW.
JOHN NELSON JAMES.	AINSWORTH RAND SPOFFORD.
JOSEPH STANLEY-BROWN.	GILBERT THOMPSON.

The General Committee held 15 regular and 2 special meetings.

The first special meeting was held December 18, 1897, "to consider the report of a conference committee upon a joint organization of the Scientific Socities of Washington." The second special meeting was held July 23, 1898, to elect a Treasurer to serve during the absence from Washington of Mr. Birnie. The average attendance at the meetings of the General Committee was 11.

The Society held 16 meetings, 13 of which were devoted to the reading and discussion of papers, one to the President's annual address, one to a discussion of the work of the Society, and one to the annual meeting for reports and election of officers. The average attendance at the 15 meetings was 22.

Thirty-two papers were presented by 24 members and one

guest. Two biographical notices of deceased members were read, viz:

CHARLES HUGO KUMMELL. ORLANDO METCALFE POE.

All meetings were held in the Assembly Hall of the Cosmos Club. One paper was published during the year, A century of geography in the United States, by Mr. Marcus Baker.

E. D. PRESTON,
J. ELFRETH WATKINS,
Secretaries.

The reports of the Treasurer and Auditing Committee were read and accepted. The Auditing Committee consisted of C. K. WEAD and E. GOODFELLOW.

ANNUAL REPORT OF THE TREASURER FOR 1898.

WASHINGTON, D. C., *December 14, 1898.*

To the Philosophical Society of Washington:

From December 11, 1897, the date of the last annual report, until July 13, 1898, Captain Rogers Birnie held the office of Treasurer, when, being suddenly ordered to the seat of the war with Spain, his accounts were transferred to the undersigned as his successor, elected by the General Committee.

This report covers the whole period from December 11, 1897, to December 14, 1898.

The income was $767; the expenses were $276.40, leaving a net gain of $490.60. To this should be added the value of coupons due December 1, 1898, not yet cut from $2,400 of Cosmos Club bonds, $60, making an actual gain of $550.60.

On August 5 the Treasurer of the Cosmos Club called in $500 of the Cosmos Club bonds of 1886, but was able to exchange therefor an equal value of bonds of the same Club of the 1891 issue, which your Treasurer took advantage of. By this transaction bonds Nos. 70, 135, 136, 159, and 185, 5.20's of 1886, were exchanged for Nos. 240 to 244, inclusive, 10.30's of 1891.

By last year's report the investments of the Society appeared to be a total of $6,100, as follows:

U. S. bonds, at 4 per cent.	$1,500
Columbia Street Railway bond, at 6 per cent.	1,000
Cosmos Club bonds, at 5 per cent.	3,600
	$6,100

These investments remain unchanged, excepting the exchange above mentioned. They are in detail as follows, and the securities are deposited in the Society's box in the vaults of the National Safe Deposit, Loan and Trust Company of this city:

Two U. S. 4 per cent. registered bonds, No. 64,596, for $500, and No. 135,639, for $1,000; one Columbia Street Railway 6 per cent. bond, No. 299, for $1,000; twenty-four Cosmos Club 5 per cent. bonds of 1886 for $100 each, Nos. 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 155, 156, 161, 162, 163, 164, 165, 166, 167, 193, 194, 195; seven Cosmos Club 5 per cent. bonds of 1891 for $100 each, Nos. 217, 240, 241, 242, 243, 244, and 245; five Cosmos Club 5 per cent. bonds of 1893 for $100 each, Nos. 1, 53, 56, 57, and 81.

The present assets of the Society are:

Face value of securities as above	$6,100 00
Cash balance with Riggs National Bank	1,183 02
Cash on hand	20 00
Interest coupons, due December 1, 1898	60 00
Unpaid dues	110 00
Total	$7,473 02

The Treasurer is aware of no outstanding liabilities. His predecessor, Captain Birnie, turned over to him on July 13, 1898, the following list of property belonging to the Society, namely:

One fine mahogany table and chair, one iron reading stand, one large blackboard.

Respectfully submitted.

BERNARD R. GREEN,
Treasurer.

DR. *The Treasurer in Account with The Philosophical Society of Washington for the Year 1898.* CR.

1898. Dec. 14	To cash balance from last annual account.		$712 42	1898. Dec. 14	By cash paid during the year:	
	To cash received during the year for dues:				For printing and binding	$69 57
	Dues for 1897	$75 00			For postage, stationery, miscellaneous printing, and clerical services	153 33
	Dues for 1898	460 00	535 00		For box rent at Safe Deposit Company	5 00
	To cash received for interest on investments:				For notary's fee	50
	On $1,500 U. S. 4 per cent. bonds	$60 00			For rent of meeting hall	48 00
	On $1,000 Columbia Railway bond	60 00			By cash balance on deposit with Riggs National Bank	1,183 02
	On $3,600 Cosmos Club bonds.	112 00	232 00		By cash on hand	20 00
			$1,479 42			$1,479 42

Respectfully submitted.

BERNARD R. GREEN, *Treasurer.*

REPORT OF THE AUDITING COMMITTEE FOR 1898.

WASHINGTON, D. C., *December 16, 1898.*

The undersigned, a committee appointed at a meeting of the Society, December 10, 1898, to audit the accounts of the Treasurer, respectfully report as follows:

We have examined the statement of receipts, including dues and interest, and find the same to be correct.

We have examined the statement of disbursements and compared it with the vouchers and find them to agree.

We have compared the balance reported by the Riggs' National Bank as on deposit December 11, 1898, and find it to agree with the amount reported by the Treasurer.

We find further that the Treasurer has received since December 11, 1898, and has in his possession checks for dues amounting to $20.

We have examined the securities in the box of the Society at the National Safe Deposit and Trust Company and find them to be as follows:

$1,500 U. S. registered 4 per cent.; $1,000 Columbia Street Railway 6 per cent.; $2,400 Cosmos Club 5 per cent. of 1886, with coupons attached of December 1, 1898; $700 Cosmos Club 5 per cent. of 1891; $500 Cosmos Club 5 per cent. of 1893, making in all $6,100, par value.

We find arrearages of dues for 1897 amounting to $20 and for 1898 amounting to $90.

CHARLES K. WEAD.
EDWARD GOODFELLOW.

The election of officers for 1899 was then held, and resulted as follows:

President................O. H. TITTMANN.

Vice-Presidents.......... { H. S. PRITCHETT. C. D. WALCOTT. G. M STERNBERG. L. F. WARD. }

Treasurer................B. R. GREEN.

Secretaries...............J. E. WATKINS. E. D. PRESTON.

MEMBERS AT LARGE OF THE GENERAL COMMITTEE.

Cyrus Adler.	H. M. Paul.
W. A. De Caindry.	Richard Rathbun.
G. W. Littlehales.	F. W. True.
J. H. Gore.	C. K. Wead.

Isaac Winston.

Mr. Dall proposed the following amendment to the Constitution:

Substitute for article III the following:

Article III. There shall be a General Committee consisting of the officers of the Society and nine other members and such of the Past Presidents of the Society resident in Washington and retaining membership as shall annually, before the first meeting in February of any year, notify the Secretary of the General Committee of their intention to attend its meetings or whose presence may be requested by a vote of the committee.

This, under the rules, was laid over for one year before action.

493d Meeting. **January 7, 1899.**

Mr. F. H. Bigelow, the retiring President of the Society, delivered the annual address; subject, The function of criticism in the advancement of science. [Published in this volume, pp. 337–366.]

494th Meeting. **January 21, 1899.**

Vice-President Sternberg in the chair.

Eighteen members present.

Mr. Sternberg made an informal communication on Radiographs, illustrating by photographs. [Not published.]

Mr. J. F. Hayford read a paper, prepared by Mr. L. A. Bauer, on The decomposition of the earth's permanent magnetic field.

Mr. C. F. Marvin read a paper on Apparatus for making meteorological observations by means of kites.

This was discussed by Messrs. Abbe, Preston, Hayford, Wead, and Sternberg.

495th Meeting. **February 4, 1899.**

Past President Eastman in the chair.

Eighteen members and guests present.

Mr. J. F. Hayford read an "informal" communication by Mr. L. A. Bauer entitled, Is the principal source of the secular variation of the earth's magnetism within or without the earth's crust?

This was discussed by Messrs. Wead, Eimbeck, Hayford, and Bigelow.

Mr. J. H. Gore read a paper entitled The beginnings of geodesy in the United States.

Remarks were made thereon by Messrs. Hayford and Eimbeck.

Mr. E. D. Preston read a paper entitled Geodetic operations in the United States. [Published in Comptes-rendus, Association Géodésique internationale, Stuttgart, 1898, Annex B, v. 1; also in Science, 1899, March 3, new series, vol. ix, no. 218; pp. 305–310; also in Petermann's Geogr. Mittheilungen, 1900, heft iv. An abstract was published in the Bulletin of the American Mathematical Society, November, 1898, 2d series, vol. v, no. 2.]

This was discussed by Messrs. W. F. King, of the Canadian High Joint Commission, Harkness, Farquhar, Hayford, and Eastman.

496th Meeting. **February 18, 1899.**

Past President Eastman in the chair.

Five members present.

Mr. Eastman gave an account of The second Washington Star catalogue.

497th Meeting. **March 4, 1899.**

President TITTMANN in the chair.

Twenty-one members and guests present.

Under the head of informal communications, Mr. TITTMANN submitted a question as to The condition of meteorological observations in Puerto Rico.

Discussed by Mr. BIGELOW.

Mr. GORE called attention to A new determination, by Bakhuyzen, of the periodic change of latitude.

Mr. BIGELOW read a review of a paper by Lemström on Electricity and vegetation. [For brief abstract see Science, 1899, March 24, new series, vol. ix, no. 221, p. 454.]

Discussed by Messrs. BRIGGS, STERNBERG, BELL, WEAD, and TITTMANN.

Mr. STERNBERG read a paper entitled Some sanitary lessons in the late war. [Published in the Journal of the American Medical Association, June 10, 1899; also as a separate.]

Discussed by Messrs. BRIGGS, BELL, BIGELOW, and TITTMANN.

498th Meeting. **March 18, 1899.**

President TITTMANN in the chair.

Twenty-six members present.

A lantern just bought for the use of the Society was exhibited and tested. Mr. True, chairman of the purchasing committee, made an informal report on the action of his committee.

There followed a brief discussion of the proposed celebration of the 500th meeting.

Mr. BIGELOW made an informal communication on Electric farming. [Not published.]

Mr. ARTEMAS MARTIN read a paper entitled Triangles whose angles are 60° or 120° and sides whole numbers. [This paper

will appear in the Mathematical Magazine, vol. ii, no. 12. For brief abstract see Science, 1899, April 14, new series, vol. ix, no. 224, p. 552.]

Discussed by Messrs. TITTMANN and BAKER.

Mr. LYMAN J. BRIGGS read a paper entitled Electrical methods of investigating the moisture, temperature, and soluble salt content of soils. [Published as Bulletin 15, Division of Soils, U. S. Department of Agriculture.]

Discussed by Messrs. C. G. ABBOTT, LITTLEHALES, RADELFINGER, and TITTMANN.

Mr. WEAD read a paper entitled Application of electricity to musical instruments. [An abstract of this paper was published in Science, 1899, April 14, new series, vol. ix, no. 224, pp. 552–553.]

Discussed by Messrs. TITTMANN and WEAD.

499th Meeting. **April 1, 1899.**

President TITTMANN in the chair.

Twenty-five members present.

Mr. PRESTON gave a brief description of the great telescope now under construction at Paris and which is to be one of the features of the World's Fair in 1900. [Not published.]

Discussion by Messrs. ABBE and HAYFORD.

Mr. LITTLEHALES read a paper entitled The prospective place of the solar azimuth tables in the problem of accelerating ocean transit. [Published, under the title Development of great circle sailing, in the United States Hydrographic Office, publication no. 90, 2d edition.]

Discussed by Messrs. TITTMANN and WINSTON.

Mr. E. G. FISCHER read a paper entitled Data relating to nickel-iron alloy. [Not published.]

Discussion by Messrs. BRIGGS, EASTMAN, ABBE, L. A. FISCHER, WINSTON, TITTMANN, PRESTON, HAYFORD, WEAD, and the author.

Mr. H. A. HAZEN read a paper entitled Electric and magnetic weather.

500th Meeting. **April 15, 1899.**

The 500th meeting of the Society was celebrated by a dinner at Rauscher's, corner Connecticut avenue and L street.

There were present F. V. Coville, President of the Biological Society; H. N. Stokes, President of the Chemical Society, and the following members:

Cyrus Adler.	J. Howard Gore.	E. D. Preston.
Marcus Baker.	B. R. Green.	H. S. Pritchett.
F. H. Bigelow.	J. G. Hagen.	G. R. Putnam.
Rogers Birnie.	William Harkness.	Richard Rathbun.
J. W. Chickering.	J. F. Hayford.	G. M. Sternberg.
F. W. Clarke.	H. L. Hodgkins.	O. H. Tittmann.
J. R. Cook.	A. F. A. King.	F. W. True.
Whitman Cross.	A. Lindenkohl.	C. D. Walcott.
W. H. Dall.	W J McGee.	J. E. Watkins.
W. A. De Caindry.	S. Newcomb.	C. K. Wead.
J. R. Eastman.	H. G. Ogden.	Isaac Winston.
Louis A. Fischer.	James Page.	C. C. Yates.
J. M. Flint.		

501st Meeting. **April 29, 1899.**

Vice-President Pritchett in the chair.

Thirty-three members present.

Mr. Preston made an informal communication on Recent geodetic operations in Spain, dwelling particularly on the measurement of base lines and the geodetic connection between Spain and Algiers. [Not published.]

Discussed by Messrs. Gore and Dall.

Mr. Hayford read a paper on A new treatment of refraction in height computations. [For brief abstract see Science, 1899, May 12, new series, vol. ix, no. 228, p. 686.]

Discussed by Messrs. Harkness, Hayford, Pritchett, Preston, Paul, Wead, and Moore.

Mr. Pritchett read a paper entitled An estimate of the population of the United States in 1900 derived from an empirical

formula. [For an abstract see Science, 1899, May 12, new series, vol. ix, no. 228, p. 686.]

Discussed by Messrs. FARQUHAR, MARTIN, and GORE.

Mr. GORE exhibited a number of lantern slides illustrating geodetic work in Spitzbergen.

502d Meeting. **May 13, 1899.**

President TITTMANN in the chair.

Twenty-two members and guests present.

Informal communications were made by Mr. WEAD on Color effect in stereoscopic pictures, by Mr. BAKER on A certain rhythmic problem, by Mr. TITTMANN on The results of tidal observations at the mouth of the Elbe, and by Mr. GORE on Some Spanish geodetic literature.

Mr. GORE read a paper on Geodetic work in Spitzbergen.

Discussed by Mr. PRESTON and the author.

Mr. SEE read a paper entitled An extension of Helmholtz's theory of the sun to the case of a heterogeneous sphere made up of gaseous layers of uniform density.

Discussed by Messrs. BAUER, WEAD, LITTLEHALES, HAYFORD, and the author.

503d Meeting. **May 27, 1899.**

Vice-President STERNBERG in the chair.

Twenty-nine members and guests present.

Mr. RADELFINGER read a paper entitled Recent progress in the theory of linear differential equations. [Published in the Bulletin of the Philosophical Society of Washington, vol. xiv, pp. 21–35; also an abstract in Science, 1899, June 16, new series, vol. ix, no. 233, p. 849.]

Discussed by Messrs. LITTLEHALES and GORE.

Mr. LOUIS D. BLISS read a paper on Some applications of Hertzian waves. [For an abstract see Science, 1899, June 16, new series, vol. ix, no. 233, p. 849.]

Discussed by Messrs. BIGELOW, LITTLEHALES, TONDORF, MAYNARD, and WEAD.

Announcement was made by the President of the deaths of three members, viz:

EDWARD GOODFELLOW, died May 7, 1899.

W. W. GODDING, died May 6, 1899.

WILLIAM LAWRENCE, died May —, 1899.

504th Meeting. **October 14, 1899.**

President TITTMANN in the chair.

Twenty-one members and guests present.

Mr. TITTMANN made an informal communication respecting certain statements in a French geographical magazine as to conditions of personal safety in Alaska.

A paper by Mr. LINDENKOHL, entitled Recent progress in oceanography, was read by the Secretary and discussed by Messrs. PAGE, PRESTON, and TITTMANN. [Published in Science, 1899, December 1, new series, vol. x, no. 257, pp. 803–807.]

Mr. GORE read a paper entitled The commercial relations of Germany and the United States.

This gave rise to an animated discussion, participated in by Messrs. WATKINS, TITTMANN, SCHOENFELD, ADLER, MAYNARD, PROCTER, WEAD, and the author.

505th Meeting. **October 28, 1899.**

President TITTMANN in the chair.

Twenty-five members and guests present.

Informal communications were made by ARTEMAS MARTIN on A method of extracting roots by successive subtractions [not

yet published], and by C. K. WEAD on Labels on objects in museums. [Not published.]

Mr. C. D. WALCOTT read a paper entitled A geological trip to Newfoundland. [Published, with the title Lower Cambrian terrane in the Atlantic province, in Proceedings of the Washington Academy of Sciences, 1900, February 14, vol. i, pp. 301–339.]

Discussed by Mr. TITTMANN and the author.

Mr. C. K. WEAD read a paper entitled Some Arab musical scales. [An abstract was published in the Proceedings of the American Association for the Advancement of Science, 1899, vol. xlviii, p. 96; also in Science, 1899, November 24, new series, vol. x, no. 256, p. 777.]

506th Meeting. November 11, 1899.

President TITTMANN in the chair.

Thirty-five members and guests present.

Informal communications were made as follows:

By Mr. ARTEMAS MARTIN, an illustration of the extraction of the fourth root by successive subtractions, being supplementary to his communication at the last meeting. [Not yet published.]

By Mr. BIGELOW, who stated that additional information had been obtained as to the percentage of cloudiness along the path of the total eclipse of May 28, 1900.

By Mr. MARCUS BAKER, on the recent Anglo-Venezuelan boundary arbitration held in Paris. [Published in the National Geographic Magazine, April, 1900, vol. xi, no. 4, pp. 129–144.]

Mr. LITTLEHALES called attention to a defect in the boundary description contained in the recent treaty respecting the Philippine islands.

Mr. R. H. STROTHER read a paper entitled Some observations on a problem in dynamics. This was illustrated by a model and by lantern slides. The paper was devoted to an explanation of the method by which a cat was able to turn over in the

air and land on its feet. [For brief abstract see Science, 1899, December 22, new series, vol. x, no. 260, p. 933.]

Discussed by Messrs. WEAD and DALL.

Mr. J. E. WATKINS read a paper entitled A chapter from the early history of mechanics.

Discussed by Mr. GORE.

507th Meeting. **November 25, 1899.**

This was a joint meeting of the Chemical and Philosophical Societies, and was held in the Assembly Hall of the Cosmos Club.

Attendance, about one hundred.

The subject of discussion was The atomic theory, concerning which five papers were read, as follows:

J. S. AMES, of Johns Hopkins University, Physical evidence in support of the atomic theory.

F. H. BIGELOW, The status of the atomic theory.

H. N. STOKES, The atomic theory from the chemical standpoint.

CLEVELAND ABBE, The relation of the ions to the atomic theory.

F. K. CAMERON, Some objections to the atomic theory.

508th Meeting. **December 9, 1899.**

President TITTMANN in the chair.

Thirty-three members and guests present.

Mr. PRESTON read a paper on The language of Hawaii. [Published in the Bulletin of the Philosophical Society of Washington, vol. xiv, pp. 37–64.]

Mr. ADLER read a biographical notice of Mr. GEORGE BROWN GOODE. [Published in this volume, pp. 396–399.]

Mr. OGDEN read a biographical notice of Mr. EDWARD GOODFELLOW. [Published in this volume, pp. 399–401.]

Mr. Bigelow read a paper entitled Results of recent exploration of the upper atmosphere. [Not published.]

Mr. Littlehales read a paper entitled Possible methods of measuring the resultant of the centrifugal and gravitational forces on the ocean. [Not published.]

Discussed by Messrs. Page, Tittmann, Bigelow, Marvin, Wead, and the author.

509th Meeting. **December 23, 1899.**

TWENTY-NINTH ANNUAL MEETING.

President Tittmann in the chair.

Twenty-two members present.

The minutes of the Twenty-eighth Annual Meeting were read and adopted.

The annual report of the Secretaries was read and accepted.

ANNUAL REPORT OF THE SECRETARIES FOR 1899.

Washington, D. C., *December 23, 1899.*

To the Philosophical Society of Washington:

The Secretaries have the honor to submit the following annual report:

The number of active members at date of last report was 115. Of this number 4 have died, 2 have resigned, and 2 were transferred to the absent list, making a total loss of 8. The gain has been: By election of new members, 5; by transfer from the absent list, 2, making a net loss of one. The present active membership is 114.

The number on the absent list at date of last report was 79. This number remains unchanged.

The list of deceased members is:

William Whitney Godding. Edward Goodfellow.
William Lawrence. Nathan Smith Lincoln.

The new members are:

Louis Denton Bliss. Charles Matthews Manly.
Thomas Jefferson Jackson See. Robert Henry Strother.
Milton Updegraff.

The following members were transferred from the active to the absent list:

Rogers Birnie. René de Saussure.

The following members resigned membership:

Walter Hough. Daniel Webster Prentiss.

The General Committee held 15 meetings, at which the average attendance was 11.

The Society held 17 meetings, of which 14 were devoted to reading and discussion of papers, one to the President's annual address, one to a banquet, and one to the annual meeting for reports and election of officers. The average attendance was 31, the largest being at a joint session with the Chemical Society on November 28, at which 100 were present.

The 500th meeting of the Society was celebrated by a banquet at Rauscher's, participated in by 39 members.

Forty papers were presented by 25 members. Biographical notices of two deceased members were read as follows:

George Brown Goode. Edward Goodfellow.

Five papers were published during the year, viz: Recent progress in geodesy, by E. D. Preston; Secular change in the direction of the terrestrial magnetic field, by G. W. Littlehales; On the comparison of line and end standards, by L. A. Fischer; Function of criticism in the advancement of science, by F. H. Bigelow; Constitution, rules, and list of members.

E. D. Preston,
J. Elfreth Watkins,
Secretaries.

The report of the Treasurer was read, accepted, and referred to an auditing committee, consisting of Messrs. Brockett and Hayford.

ANNUAL REPORT OF THE TREASURER FOR 1899.

WASHINGTON, D. C., *December 23, 1899.*

To the Philosophical Society of Washington:

I have the honor to submit my annual report for the past year, embracing the period between December 14, 1898, and December 20, 1899.

The income for the year has consisted of the dues of members and the interest on the investments of the Society in bonds of the United States, Cosmos Club, and Columbia Railway of this city, as follows:

Dues of members, 1897	$10 00	
1898	50 00	
1899	435 00	
		$495 00
Interest on $1,500 United States 4 per cent. bonds		75 00
Interest on $3,500 Cosmos Club bonds		227 28
Interest on $1,000 Columbia Railway bond		60 00
		$857 28
One Cosmos Club bond, $100 of 1886, called in		100 00
Total receipts		$957 28

Disbursements have been made as follows:

Publishing the Bulletin	$479 54
Postage, stationery, miscellaneous printing, clerical service, notices, etc.	186 53
Expenses of 500th meeting	35 35
Purchase of electric stereopticon	392 70
Miscellaneous expenses on ditto	29 68
Rent of safe-deposit box	5 00
Rent of hall, Cosmos Club	45 00
Total expenditures	$1,173 80

STATEMENT OF ACCOUNT.

Balance on hand at date of last annual report	$1,203 02
Receipts as above, present year	$957 28
	$2,160 30
Expenditures as above, present year	1,173 80
Cash balance on hand	$986 50

The investments of the Society are at present as follows:

4 per cent. United States bonds	$1,500 00
Cosmos Club bonds	3,500 00
Columbia Railway bond	1,000 00
Total	$6,000 00

Very respectfully,

BERNARD R. GREEN,
Treasurer.

REPORT OF THE AUDITING COMMITTEE FOR 1899.

WASHINGTON, D. C., *January 6, 1900.*

To the Philosophical Society of Washington:

The committee appointed to audit the accounts of the Treasurer begs leave to report that the statement of receipts, including dues and interest, has been examined and found correct, that the disbursements and checks agree with the vouchers, and that the balance reported by the Riggs National Bank as on deposit December 20, 1899, is the same as that stated by the Treasurer at the annual meeting.

The securities are found in the box of the Society at the National Safe Deposit, Saving and Trust Company to be as follows:

United States 4 per cent. bonds, 1877	$1,500
Columbia R. R. 6 per cent. bonds, 1894, with coupon, April 1, 1900	1,000
Cosmos Club 5 per cent. bonds, 1886, with coupon, June 1, 1900	1,800
Cosmos Club 5 per cent. bonds, 1891, with coupon, January 31, 1900	700
Cosmos Club 5 per cent. bonds, 1893, with coupon, January 31, 1900	1,000
	$6,000

Arrearages of dues for 1898 amount to $30, and those for 1899 amount to $110.

PAUL BROCKETT.
JOHN F. HAYFORD.

Elections were then held with the following result:

President........	G. M. Sternberg.	
Vice-Presidents...	H. S. Pritchett. Richard Rathbun.	C. D. Walcott. L. F. Ward.
Treasurer........	B. R. Green.	
Secretaries.......	E. D. Preston.	J. Elfreth Watkins.

MEMBERS AT LARGE OF THE GENERAL COMMITTEE.

Cyrus Adler.	C. F. Marvin.
W. A. De Caindry.	H. M. Paul.
J. H. Gore.	F. W. True.
G. W. Littlehales.	C. K. Wead.

Isaac Winston.

The amendment to the Constitution proposed by Mr. Dall at the last annual meeting was then considered.

Moved by Mr. Baker to substitute for the proposed amendment the present article III, striking out the words "*ex-Presidents of the Society*," so that it would read: "There shall be a General Committee consisting of the officers of the Society and nine other members." This motion was lost by a vote of *seven* for and *eight* against it.

The original amendment of Mr. Dall was then adopted unanimously.

Article III therefore now reads as follows:

There shall be a General Committee, consisting of the officers of the Society and nine other members and such of the Past Presidents of the Society resident in Washington and retaining membership as shall annually, before the first meeting of February of any year, notify the Secretary of the General Committee of their intention to attend its meetings or whose presence may be requested by a vote of the committee.

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